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THE DETERMINATION OF DEFORMATION MODULUS WITHIN A GRANIT.. GNEISS - PARRY SOUND

..port No 84-169-K

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ABSTRACT

A borehole dilatometer was utilized in determining the in situ deformation modulus of a granitic-gneiss located south-east of Parry Sound. Tests were conducted in vertical and horizontal holes to assess both fractured and unfractured zones. Average modulus values of 3.77 x 10^4MPa and 3.29 x 10^4MPa were obtained respectively for vertical and horizontal boreholes in unfractured rock. Average modulus values of approximately 1.42 x 10^4MPa were obtained in the fractured zones.

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THE DETERMINATION OF DEFORMATION MODULUS WITHIN A GRANITIC GNEISS - PARRY SOUND

1.0 INTRODUCTION

An in situ borehole modulus testing program was carried out during the period from September 13 to September 17, 1982, within a granitic gneiss rock outcrop. The test site was located approximately 40 kilometres south-east of Parry Sound, Ontario, on the eastern side of Georgian Bay (Figure 1). The objective of this program was to field test a borehole dilatometer in both fractured and unfractured rock and to obtain the corresponding in situ deformation moduli. Tests were conducted at varying depths in both vertical and horizontal boreholes.

This task was undertaken to determine the effectiveness of the borehole dilatometer in future determinations of excavation damage within the Underground Research Laboratory (URL) near Pinawa, Manitoba. This project was funded by the Rock Sciences Section, Civil Research in support of the technical assistance program to AECL.

The Colorado School of Mines cell (CSM) was chosen as the instrument by which a rock mass could be assessed with respect to delineating zones of varying moduli. Fractured zones provided lower modulus values while sound, unfractured rock provided higher values. The dilatometer (CSM cell) and pressurizing system was built by Ontario Hydro's Rock Sciences Section based on specifications provided by Dr. W. Hustrulid (Department of Mining, Colorado School of Mines).

2.0 BOREHOLE MODULUS DETERMINATION

2.1 Background

Panek et al (1964) developed a borehole dilatometer called the Cylindrical Pressure Cell (CPC) to determine the modulus of rigidity for rock. Due to certain operational problems, such as permanent deformation of the copper membrane during pressurization in a borehole, Hustrulid and Hustrulid (1975) developed the Colorado School of Mines (CSM) cell to overcome some of the problems inherent in the CPC system.

2.2 Testing Equipment

In general, the modulus testing system comprises a high pressure generator with vernier scale, high pressure steel tubing and valves, pressure transducer and a dilatometer (Figure 2). The dilatometer (CSM cell), is the heart of the system and consists of an adiprene membrane and a steel shaft having both a fixed and threaded steel end cap. The cell described here was developed to be used in an EX borehole (3.8 cm in diameter) while applying pressure over a length of approximately 17cm. Fluid in the system is pressurized with the pressure generator, which in turn expands the dilatometer and applies a pressure to the inside wall of a borehole. The system is closed and has the capacity of applying and measuring pressures up to about 70 MPa.

2.3 Calculations

The modulus of deformation is obtained by utilizing mathematical analysis to compare the pressure-volume relationships of a known material such as aluminum or steel to that of a rock mass of unknown properties. It is assumed that the calibration cylinder and the rock mass will both respond in an analogous manner during the pressurizing process. Although both expansion and contraction information is recorded, the expansion, which yields the compression modulus, is used in the calculations required to determine the deformation modulus. Weathering and fracturing within the rock mass reduce the energy storage capabilities of the rock mass and thereby reduces the slope value of the pressure/volume relationship and therefore the calculated rebound modulus. The deviation between the increasing and decreasing slopes gives some indication as to the degree of microfracturing experienced within that particular segment of the hole.

The complete derivations of equations required for the calculation of experimental results is provided by Hustrulid and Hustrulid (1975). Only the basic equations are presented here. The systematic progression of calculations is shown in Figure 3.

Step 1. The pressure-volume relationship (Mc) for the cylinder alone is calculated:

$$Mc = \frac{\gamma Gc}{\pi L\, r_{ic}^{2}\left[\frac{1+\beta c}{1-c} - \frac{2\mu c\ \beta c}{1-\beta c}\right]}$$

where γ = volume of fluid displaced per turn

Gc = modulus of rigidity of the calibration cylinder

L = length of membrane

r_{ic} = inner radius of calibration cylinder

μ = Poisson's ratio

$\beta c = (r_{ic}/r_{oc})^2$

r_{oc} = outer radius of calibration cylinder

Step 2. The slope of the pressure-volume curve (Mm) for the system plus the calibration cylinder is determined.

Step 3. The stiffness of the pressurizing system (Ms) alone is calculated:

$$Ms = \frac{Mc\ Mm}{Mc - Mm}$$

Step 4. The slope of the pressure-volume curve (Mt) for the pressurized system plus rock is determined.

Step 5. The pressure-volume relationship (Mr) for the rock alone is calculated:

$$Mr = \frac{Ms\ Mt}{Ms - Mt}$$

Step 6. The modulus of rigidity (Gr) is calculated:

$$Gr = \frac{Mr\ \pi Lri^2}{\gamma}$$

Step 7. The deformation modulus (E) can be calculated if Poisson's radio (μ) is known (or can be assumed).

$$E = 2(1 + \mu)\ Gr$$

Only the straight line portions of the pressure-volume curves are utilized in the determination of Mm and Mt. The initial curved portions of the graphs are neglected since they represent the deformation and seating of the adiprene membrane. A computer program has been prepared for ease of performing the required calculations.

2.4 Field Testing

Two vertical and two horizontal EX (3.81 cm diameter) boreholes were drilled using a Winkie portable drill to depths of about 5 metres each. Six short EX holes were also drilled to depths of approximately 0.5 metres to enable experimentation with dilatometer

fracturing of the rock mass to determine its potential for in situ stress determinations. A plan view showing the locations of all drill holes is provided in Figure 4.

Four tests (Figure 5) were carried out vertically in borehole 1 at depths of 3.35m (Test 1), 2.74m (Test 2), 2.13m (Test 3) and 0.15m (Test 4). All tests were performed in unfractured zones except for Test 4 which was purposely set in a zone which contained a horizontal fracture. This was done to determine what effect, if any, a fracture would have on the cell membrane. It has been reported (Patricio and Beus, 1976), that cell membranes should not be tested in fractured zones since failure can occur as a result of the membrane extending into an open fracture and rupturing. Four horizontal tests (Figure 6) were carried out in borehole 3 at depths of 3.96m (Test 5), 2.59m (Test 6), 1.42m (Test 7) and 0.76m (Test 8). Three tests (Figure 5) were performed horizontally in borehole 4 at depths of 1.10m (Test 9), 4.72 (Test 10) and 2.74m (Test 11). In both drillholes 3 and 4, the rock overburden thickness increased from the borehole collar to the bottom of the borehole. Two tests (Figure 6) were undertaken vertically in borehole 2 at depths of 2.74m (Test 12) and 1.73m (Test 13). Of the six short vertical holes which were drilled, only holes 7 (Test 14) and 10 (Test 15) were tested due to a lack of time. Tests 14 and 15 both contained horizontal fractures within the test zone.

Prior to testing, the dilatometer was calibrated in an aluminum thick-walled cylinder. The cylinder had an inner diameter of 3.81cm, an outer diameter of 11.44 cm and an overall length of 30.48cm. In general, three cycles were run during each calibration, with only the last two recorded. The first cycle was used to seat the dilatometer in the cylinder. After calibration, the dilatometer was lowered to the bottom of the borehole using placement rods. Once again, three cycles were used with only the last two recorded. Each cycle took approximately five minutes to complete. For modulus determinations, average pressures of approximately 35 MPa were used at the top of each cycle while pressures of 2 to 5 MPa were used to secure the dilatometer in the borehole. Pressures of up to 44.0 MPa were used to fracture the rock in boreholes 3 (Tests 7 and 8), 2 (Test 13), 7 (Test 14) and 10 (Test 15). Subsequent to testing, calibrations were repeated to verify the original calibrations. Calibrations were not required after each test, but were performed at the end of the day as a minimum. All data was recorded by reading pressures for each turn of the pressure generator. The vernier scale of the pressure generator was used to obtain an exact turn measurement. Each turn related to a known volume of fluid, which was determined prior to testing. As a result, the dilatometer field test provided a volume/pressure relationship, which in turn was used to calculate the rock mass modulus. For completeness, the curves of all rock mass and calibration tests are provided in Appendix A.

During the course of the testing program, it was necessary to increase the length of the high pressure tubing from approximately 9 metres to approximately 17 metres. This was undertaken between Tests 8 and 9, to enable testing horizontal borehole No 4 from the top of the slope (testing on the slope at this location was very difficult to carry out). The system was re-calibrated subsequent to making the alterations.

In an effort to obtain impressions of the mechanically induced fractures, electrical tape was wrapped around the dilatometer membrane prior to testing. To orient the potential feature, the placement rods were marked to correspond to a known compass bearing. Tests 13 and 14 were conducted with electrical tape wrapped around the membrane.

2.5 Discussion of Results

The calculated results of tests performed in boreholes 1,2,3,4,7 and 10 are shown in Table 1. The table provides the depth of each test, direction, ratio of Mt/Ms and the deformation modulus (E).

The Mt/Ms ratio, which is the value of the pressure-volume slope for the pressurized system and rock divided by the stiffness value obtained for the pressurized system alone, is very important in the determination of the validity of modulus results. Koopmans and Hughes (1983) performed a sensitivity analysis and determined that the modulus value is essentially unaffected by system stiffness provided that the Mt/Ms ratio is approximately 0.91 or lower. As indicated in Table 1, no values exceeded 0.90, which suggested that all moduli results were uneffected by system stiffness. It was noted that even though the system stiffness, Ms, decreased in value as a result of increasing the length of the high pressure tubing, the overall stiffness was still high enough to provide valid results (ie Mt/Ms < 0.91). In this analysis, values below 2.25×10^4 MPa were treated as being influenced by discontinuities, while values above 2.25×10^4 MPa were considered to be uneffected by discontinuities. In general, values below 2.25×10^4 MPa resulted from tests which were performed in zones containing fractures.

Modulus values were averaged together for both vertical and horizontal tests in order to obtain a representative in situ rock mass deformation modulus. By averaging results above 2.25×10^4 MPa the deformation modulus calculated for vertical tests was 3.77×10^4 MPa and 3.29×10^4 MPa for horizontal tests. The results have been determined to be accurate with no apparent percentage errors related to potential system stiffness problems.

A leakage problem, which occurred within the pressure generator itself, was attributed to wearing of the teflon seals during normal piston movement. The problem was temporarily resolved by sealing around the teflon seals with teflon tape. Although this improvision proved to be successful for a short term, it was by no means a permanent solution to the problem. This situation was later rectified by using Poly-Pak Paking in place of teflon seals. (Koopmans and Hughes, 1983).

During the testing program, it was noted that the membrane began to leak at low pressures. Investigations indicated that the standard steel shaft had permanently elongated as a result of repeated testing. This problem was later overcome by using a heat-treated stainless steel dilatometer shaft (Koopmans and Hughes, 1983).

The granitic gneiss rock mass was successfully fractured by pressurizing the dilatometer in a borehole. These mechanically-induced fractures were easily visible on the electrical tap which was wrapped around the dilatometer. Two parallel fractures were noted 180 degrees apart running along the full length of the dilatometer. Figures 9 and 10 show the imprints of fractures left on the tape after it was removed and laid flat. The induced fractures consistently ranged in the N55 degrees W to N60 degrees W direction. No stress analysis was performed at this time, since it was beyond the scope of this program.

Modulus testing was successfully conducted in zones which were known to contain fractures. These fractures were recorded on electrical tape and allow one to obtain the direction and dip of joints which intersect the borehole.

3.0 CONCLUSION

A borehole dilatometer was used to obtain the modulus of deformation in fractured and unfractured zones both vertically and horizontally within a granitic gneiss outcrop located south-east of Parry Sound, Ontario. Mechanical fracturing of the rock mass was successfully performed as a preliminary investigation to examine the possibility of measuring in situ stresses using hydraulic fracturing principles. The modulus values obtained appear to have been unaffected by rock mass/system stiffness interactions.

ACKNOWLEDGEMENTS

The authors wish to thank Mr. R. Dundas, Transmission Environment Supervisor with Ontario Hydro's Georgian Bay Regional office for providing a suitable site in which to carry out the testing program. Dr. W. Hustrulid is also acknowledged for providing valuable information relating to equipment fabrication and testing procedures.

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TABLE 1

FIELD TESTING RESULTS

Test No	Hole No	Depth(m)	Hole Direction	Mt/Ms	Deformation Modulus (E) x 10^4 MPa	Comments
1	1	3.35	vertical	.896	3.85	
2	1	2.74	"	.900	3.62	
3	1	2.13	"	.897	3.95	
4	1	0.15	"	.661	0.89	- horizontal fracture in zone
5	3	3.96	horizontal	.891	3.71	
6	3	2.59	"	.876	3.31	
7	3	1.42	"	.806	1.94	- rock mechanically fractured
8	3	0.76	"	.787	1.72	- rock mechanically fractured
9	4	1.10	"	.871	2.74	
10	4	4.72	"	.881	3.04	
11	4	2.74	"	.884	3.11	
12	2	2.74	vertical	.855	2.41	
13	2	1.73	"	.900	3.65	- mechanically fractured after modulus testing
14	7	0.13	"	.781	1.45	- horizontal fracture in zone - rock mechanically fractured
14 (Con't)	7	0.13	"	.778	1.48	- horizontal fracture in zone - rock mechanically fractured
15	10	0.13	"	.716	1.05	- horizontal fracture in zone - rock mechanically fractured

FIGURE 1
TEST SITE LOCATION

164510-RD

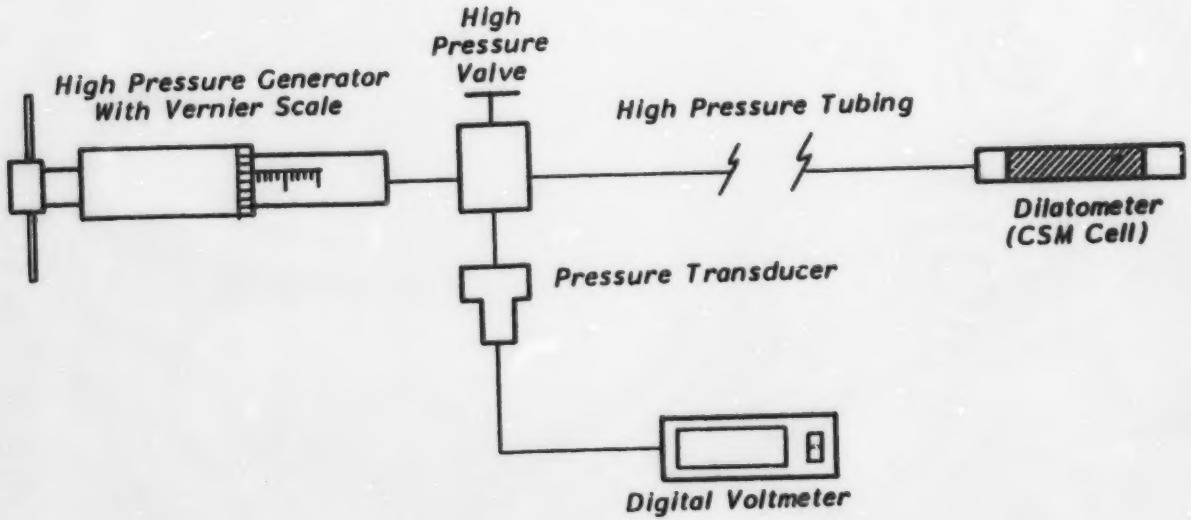

FIGURE 2

SCHEMATIC OF MODULUS TESTING SYSTEM

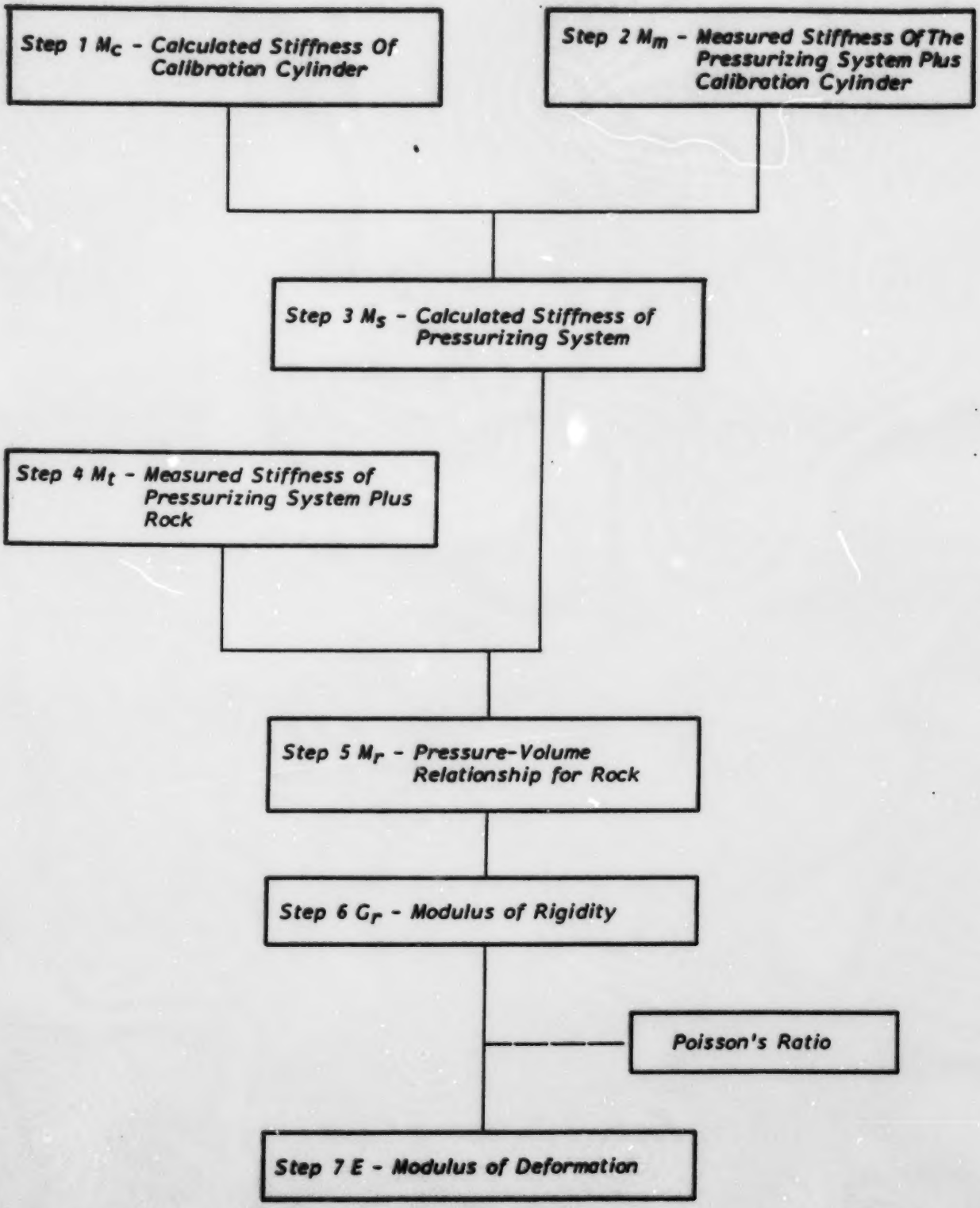
Step 1 M_c - Calculated Stiffness Of Calibration Cylinder
Step 2 M_m - Measured Stiffness Of The Pressurizing System Plus Calibration Cylinder
Step 3 M_s - Calculated Stiffness of Pressurizing System
Step 4 M_t - Measured Stiffness of Pressurizing System Plus Rock
Step 5 M_r - Pressure-Volume Relationship for Rock
Step 6 G_r - Modulus of Rigidity
Poisson's Ratio
Step 7 E - Modulus of Deformation

FIGURE 3

SYSTEMATIC PROGRESSION OF CALCULATIONS

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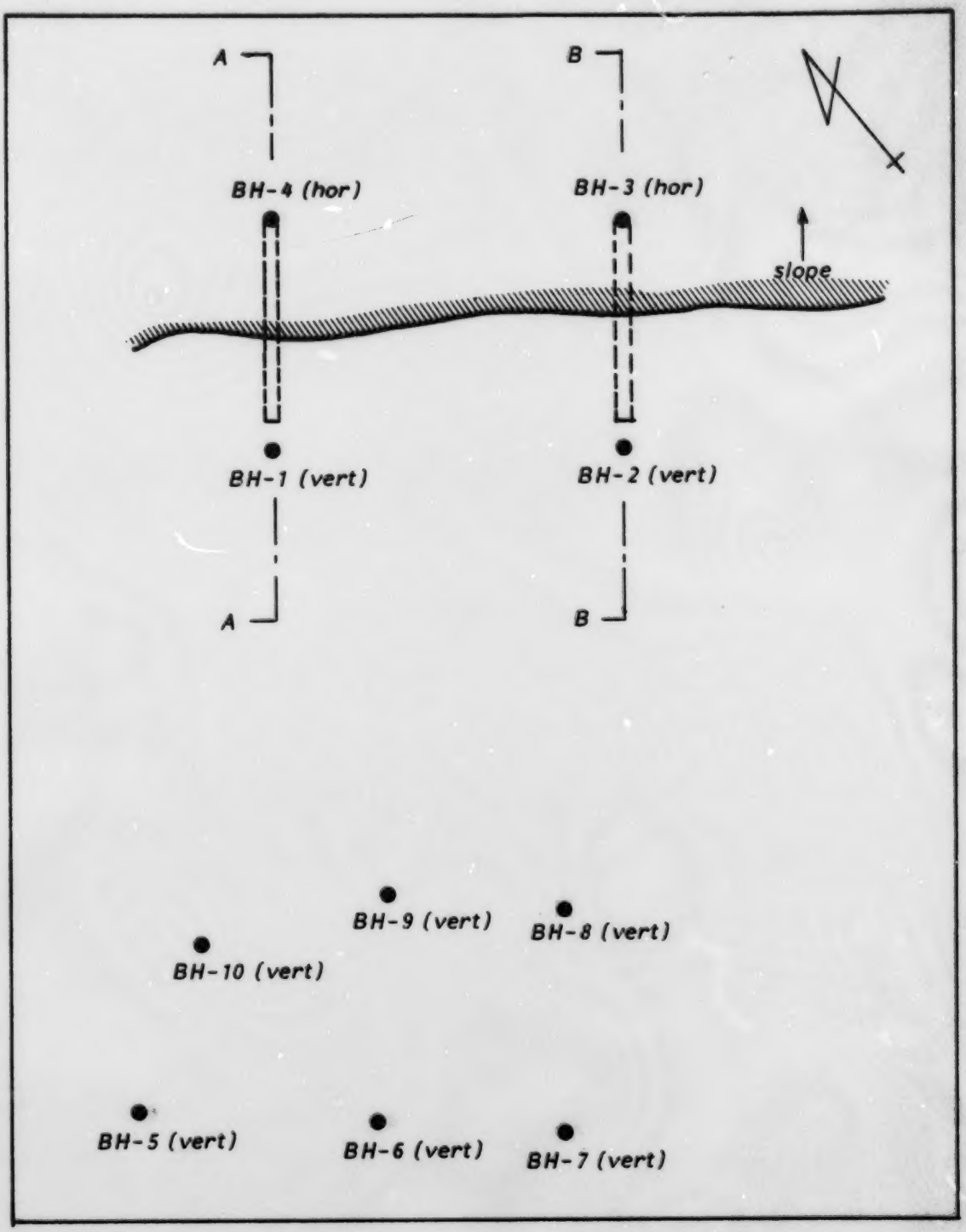


FIGURE 4

PLAN VIEW OF TESTING HOLES (NTS)

164511-RD

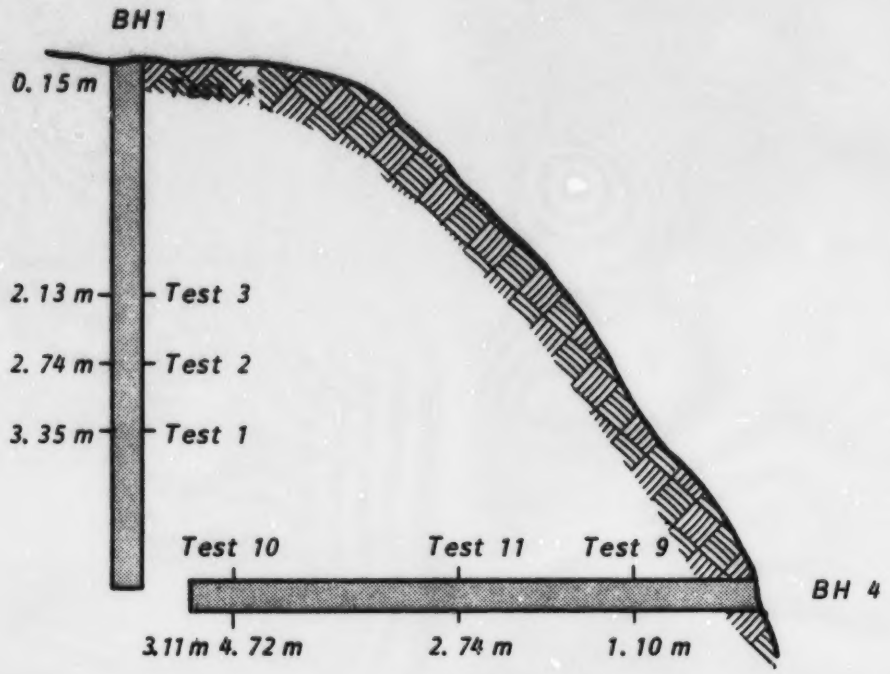


FIGURE 5

SECTION A-A: TEST LOCATIONS IN BOREHOLES 1 AND 4

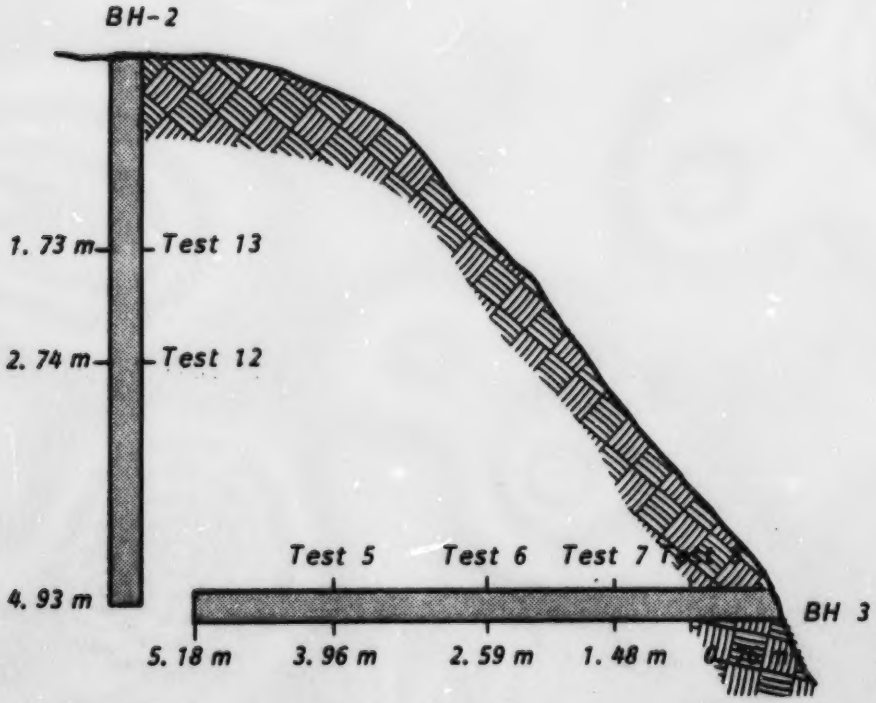


FIGURE 6

SECTION B-B: TEST LOCATIONS IN BOREHOLES 2 AND 3

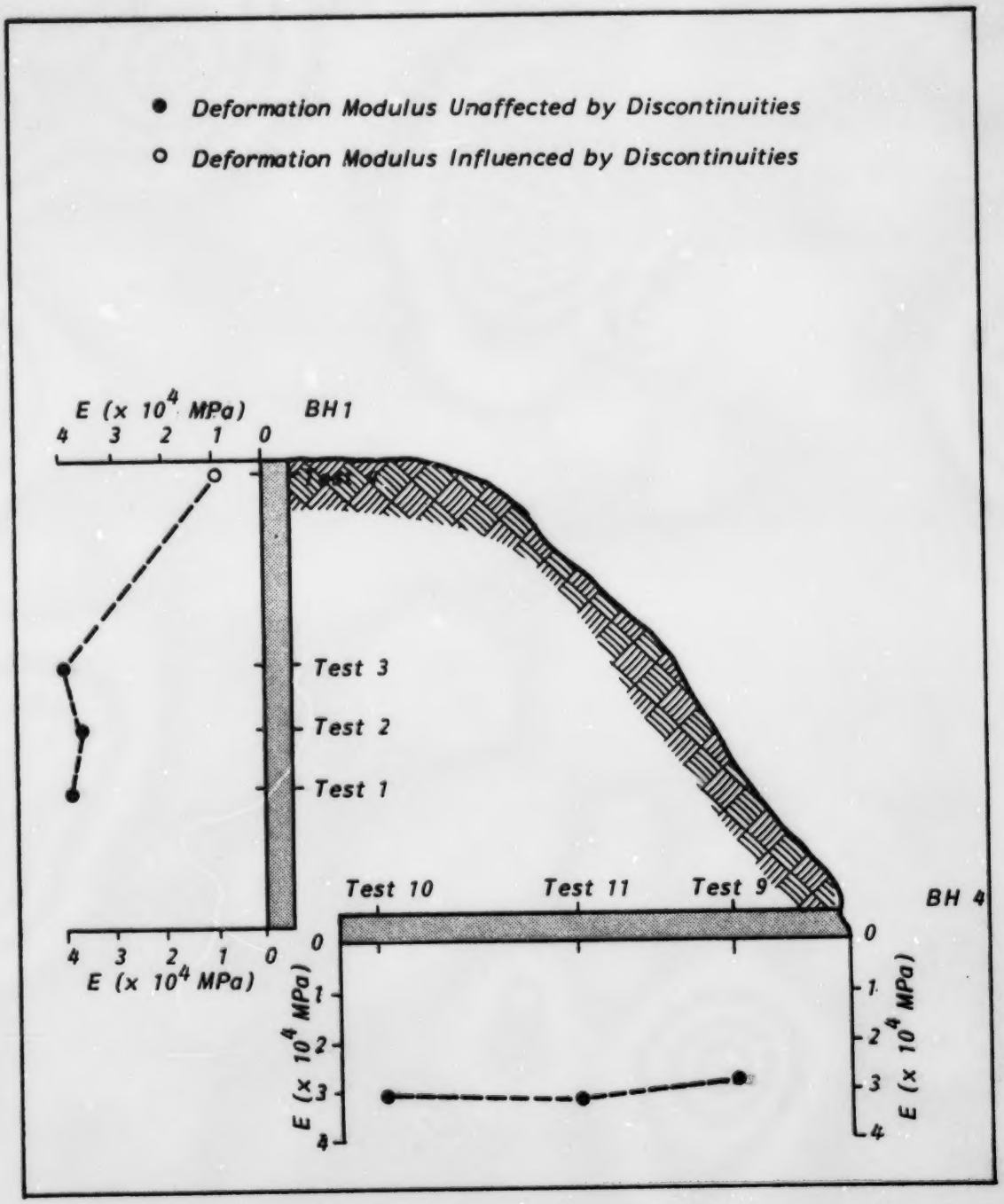


FIGURE 7

SECTION A-A: DEFORMATION MODULUS (E) VERSUS DEPTH - BH-1 AND BH-4

164513-RD

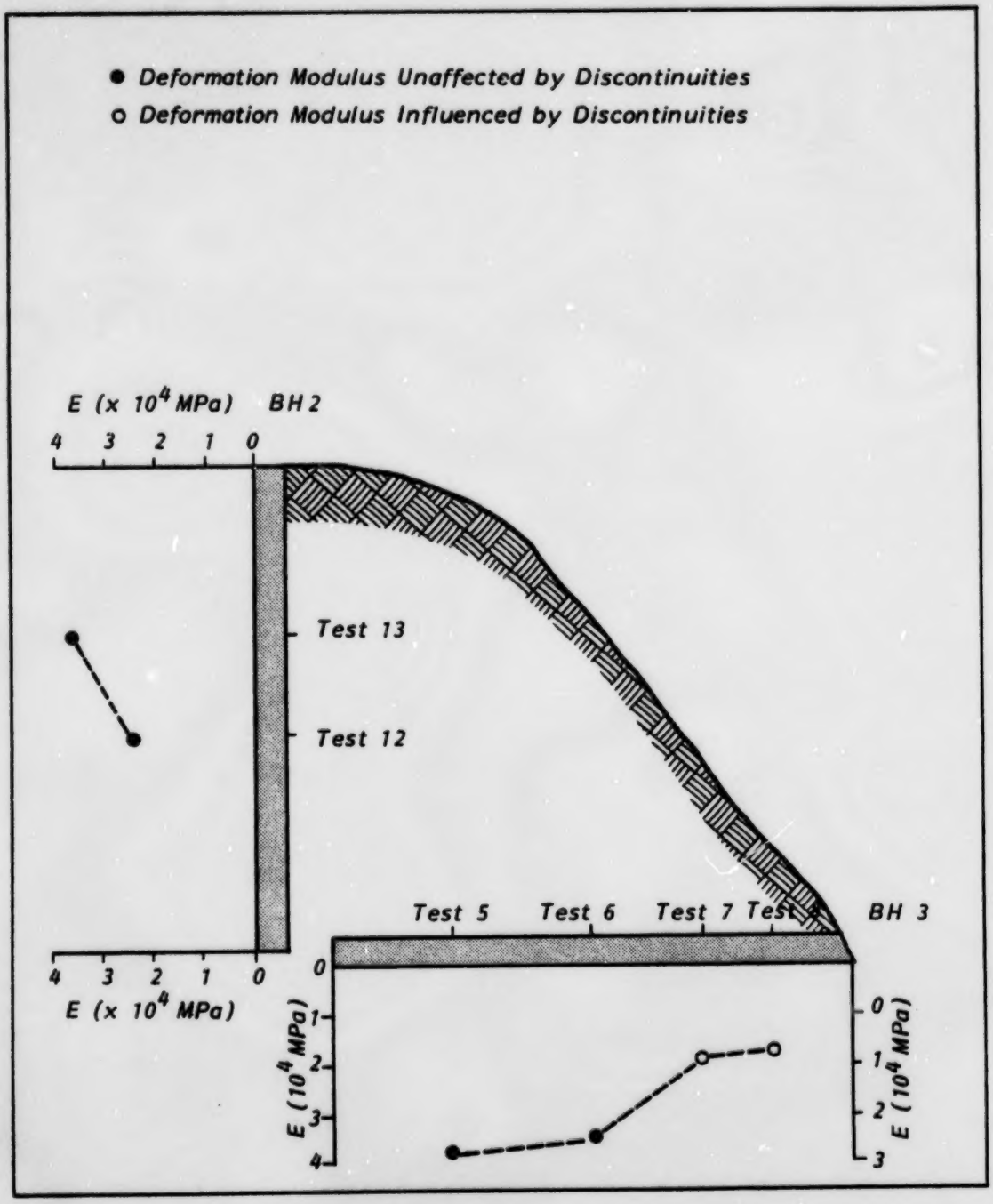


FIGURE 8

SECTION B-B : DEFORMATION MODULUS (E) VERSUS DEPTH - BH 2 AND BH-4

164514-RD

FIGURE 9
DILATOMETER INDUCED FRACTURES IN BOREHOLE 7 (ACTUAL SIZE)

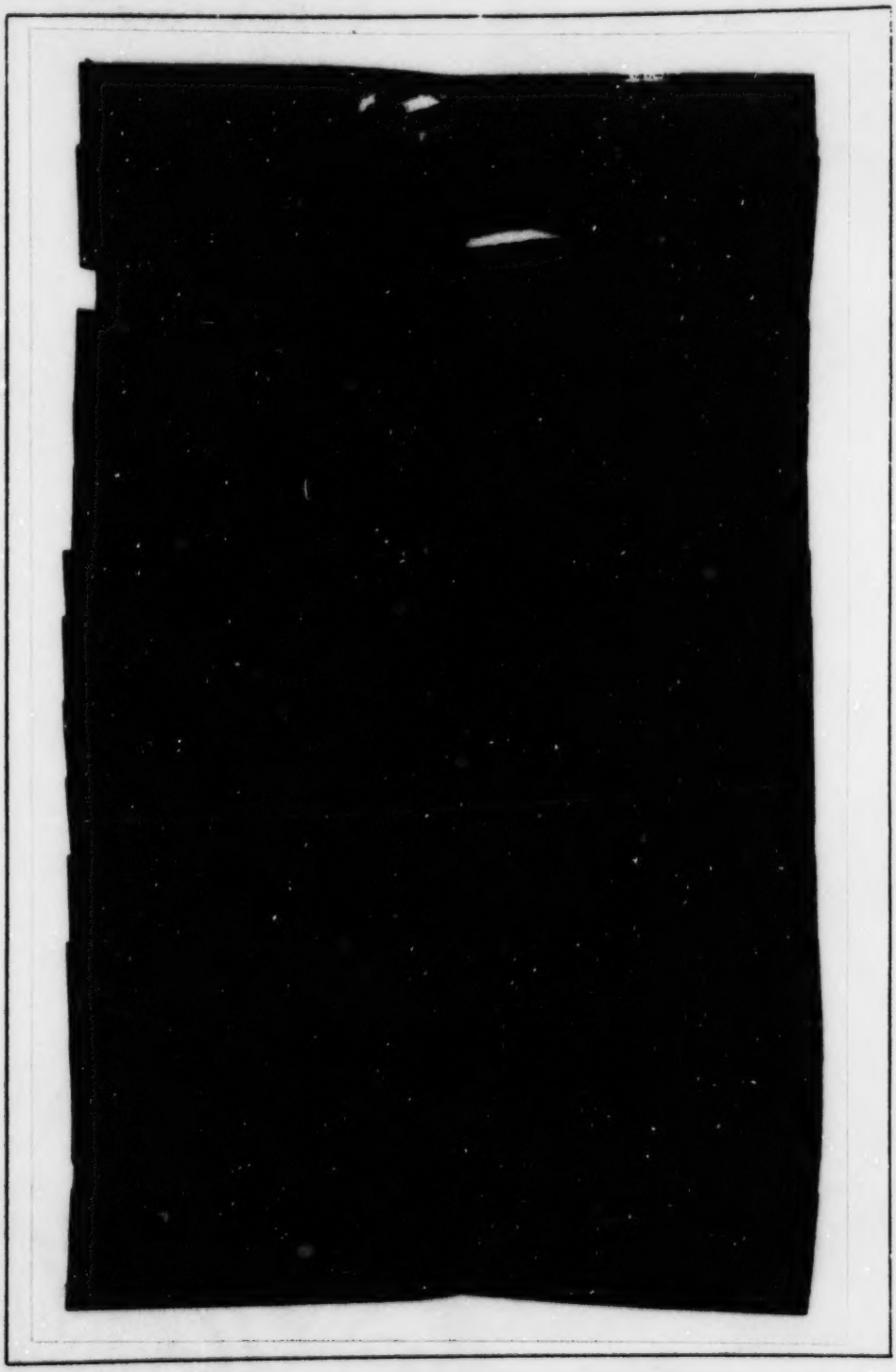
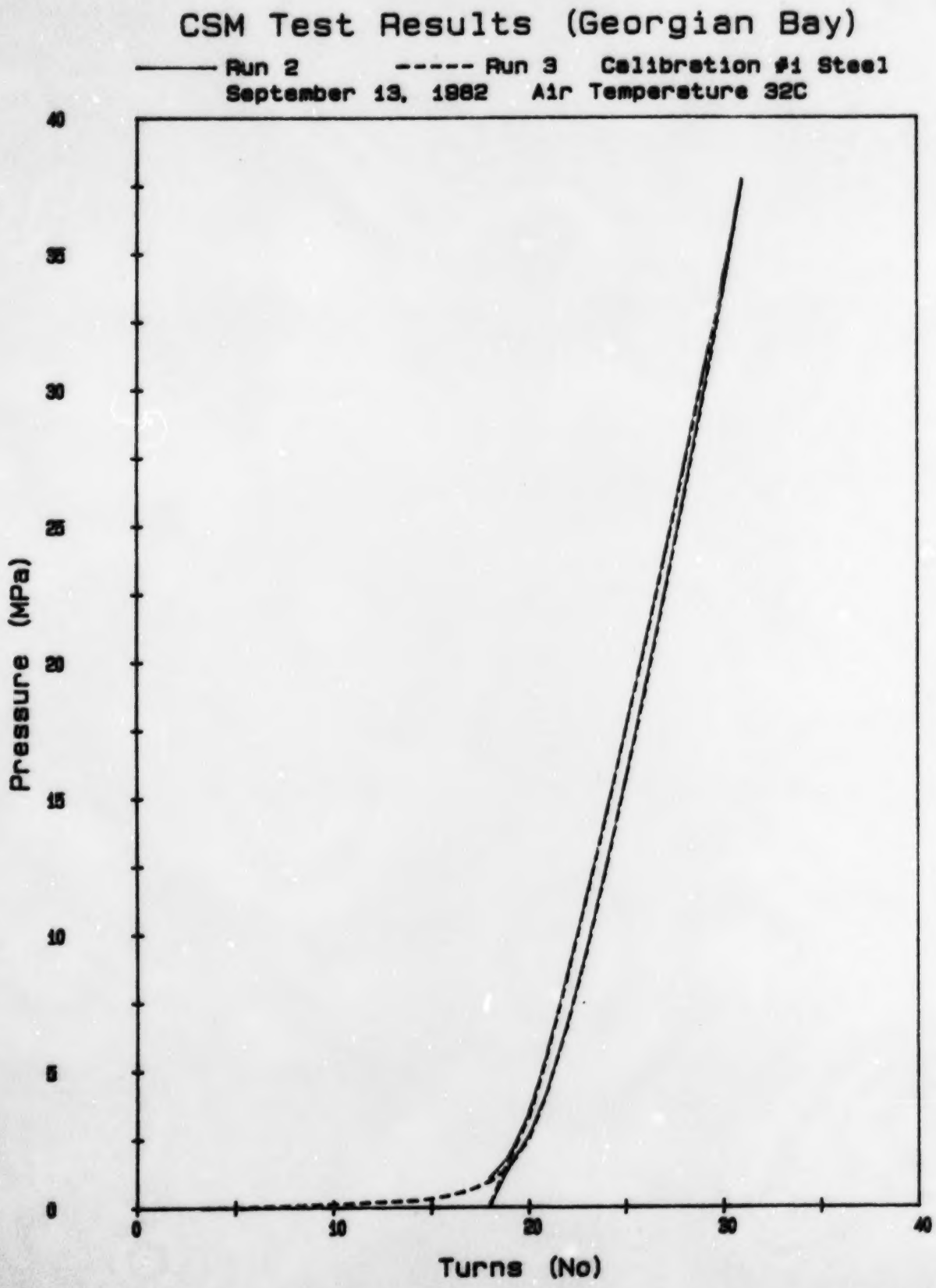


FIGURE 10

DILATOMETER INDUCED FRACTURES IN BOREHOLE 10 (ACTUAL SIZE)

APPENDIX A


CSM Test Results (Georgian Bay)
Run 2
Run 3
Calibration #1 Steel
September 13, 1982
Air Temperature 32C
Pressure (MPa)
0
5
10
15
20
25
30
35
40
0
10
20
30
40
Turns (No)

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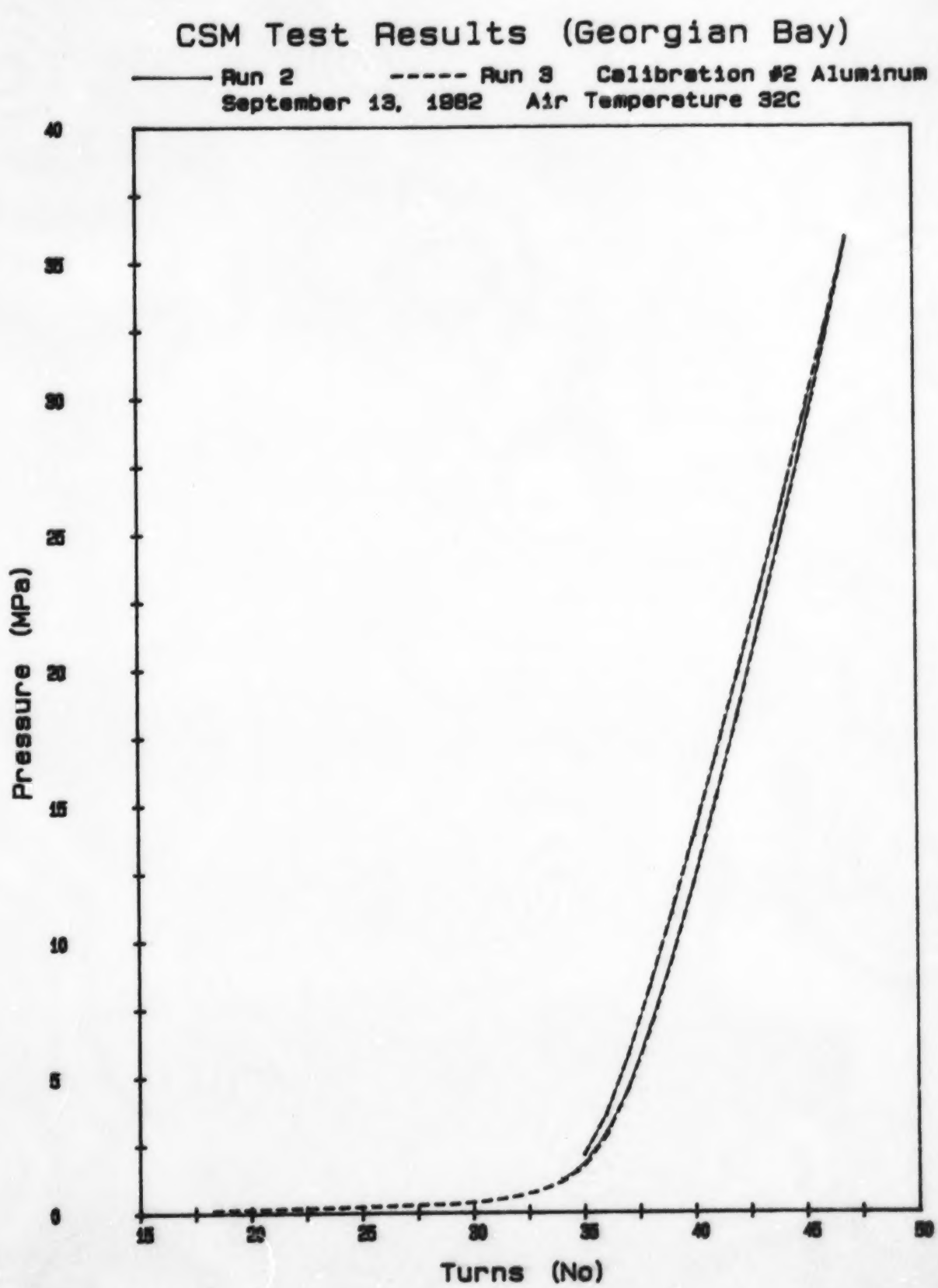
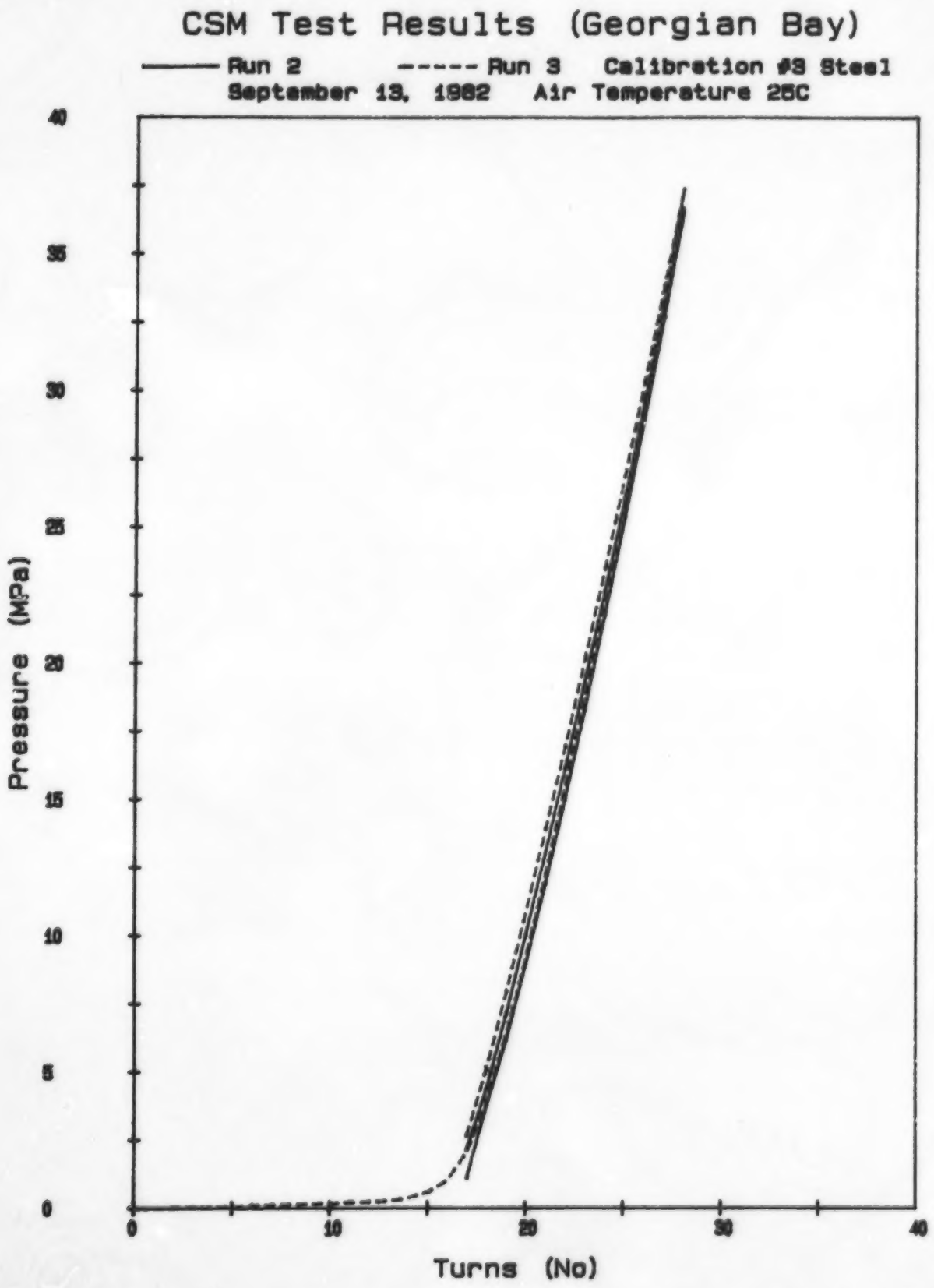
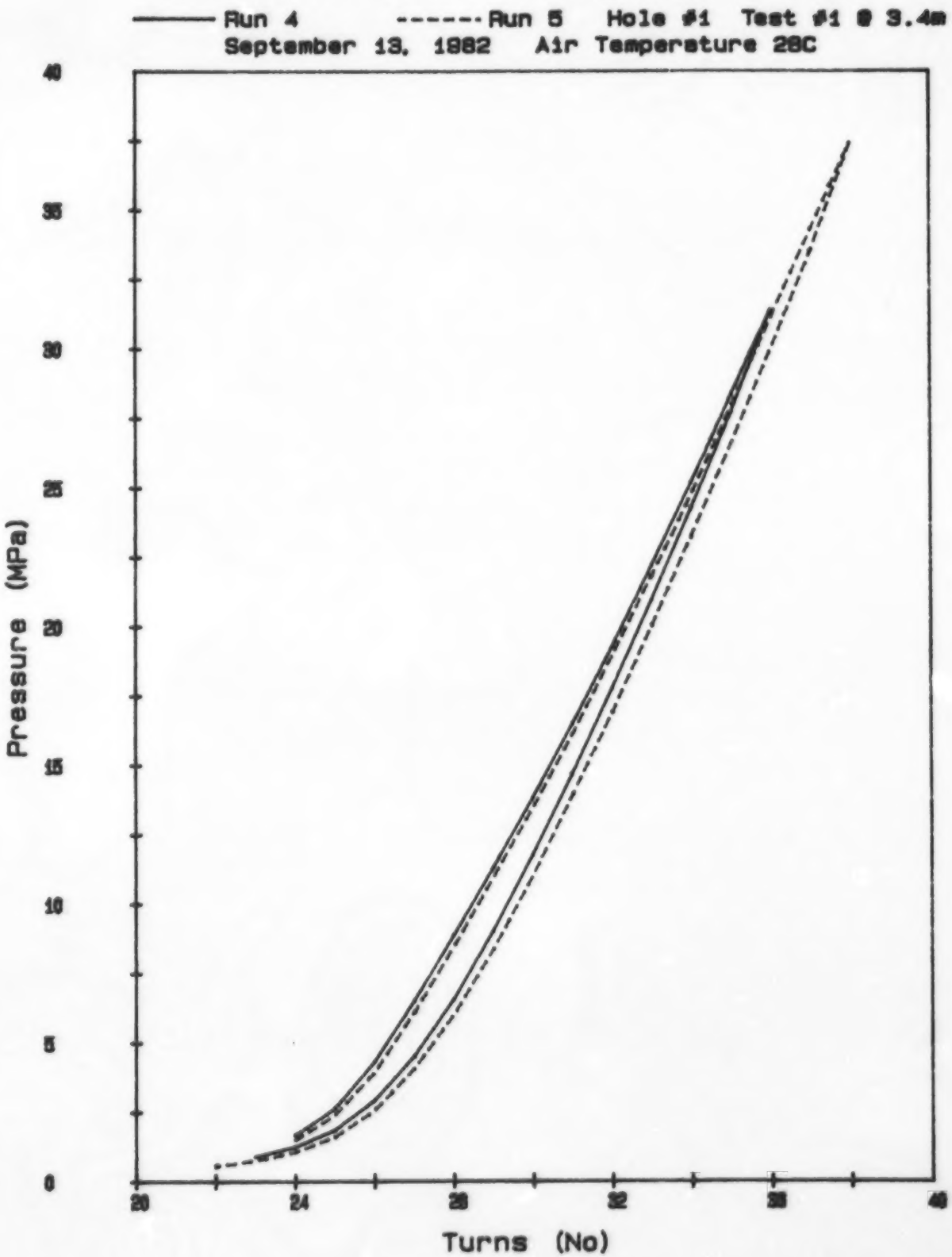

CSM Test Results (Georgian Bay)
Run 2
Run 3
Calibration #2 Aluminum
September 13, 1982
Air Temperature 32C
Pressure (MPa)
0
5
10
15
20
25
30
35
40
Turns (No)
15
20
25
30
35
40
45
50

84-169


CSM Test Results (Georgian Bay)
Run 2
Run 3
Calibration #3 Steel
September 13, 1982
Air Temperature 25C
Pressure (MPa)
0
5
10
15
20
25
30
35
40
Turns (No)
0
10
20
30
40

CSM Test Results (Georgian Bay)



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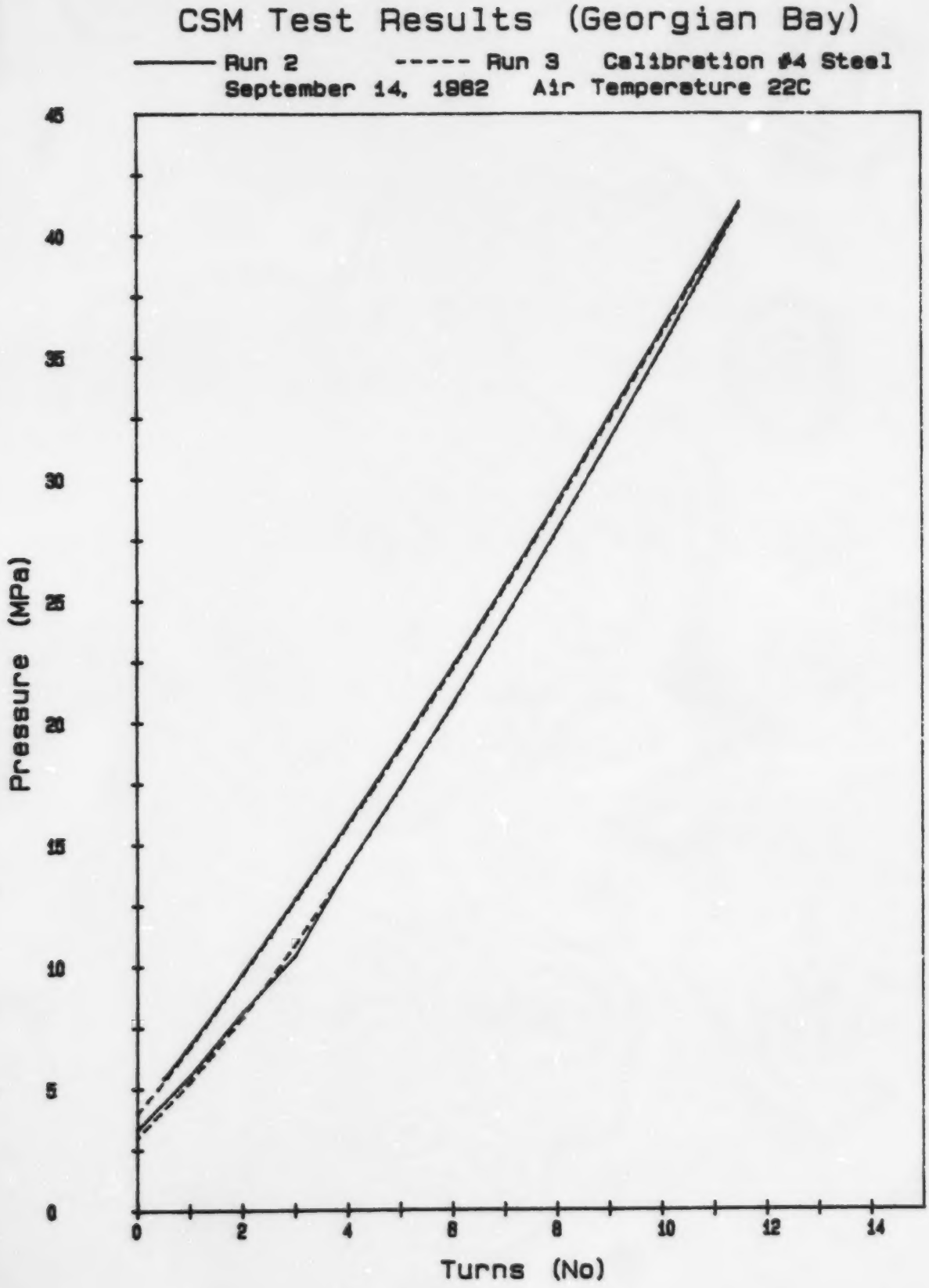

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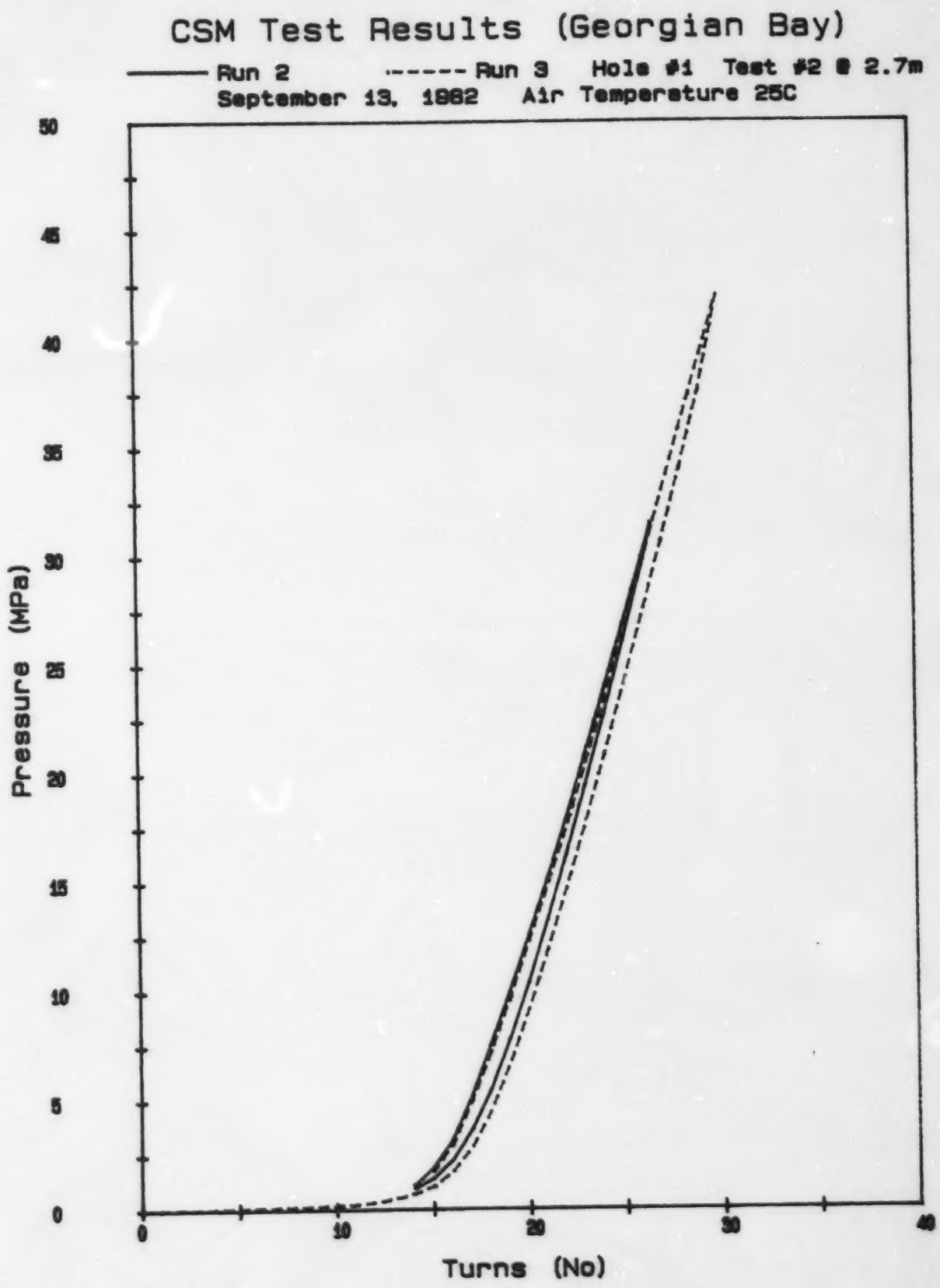
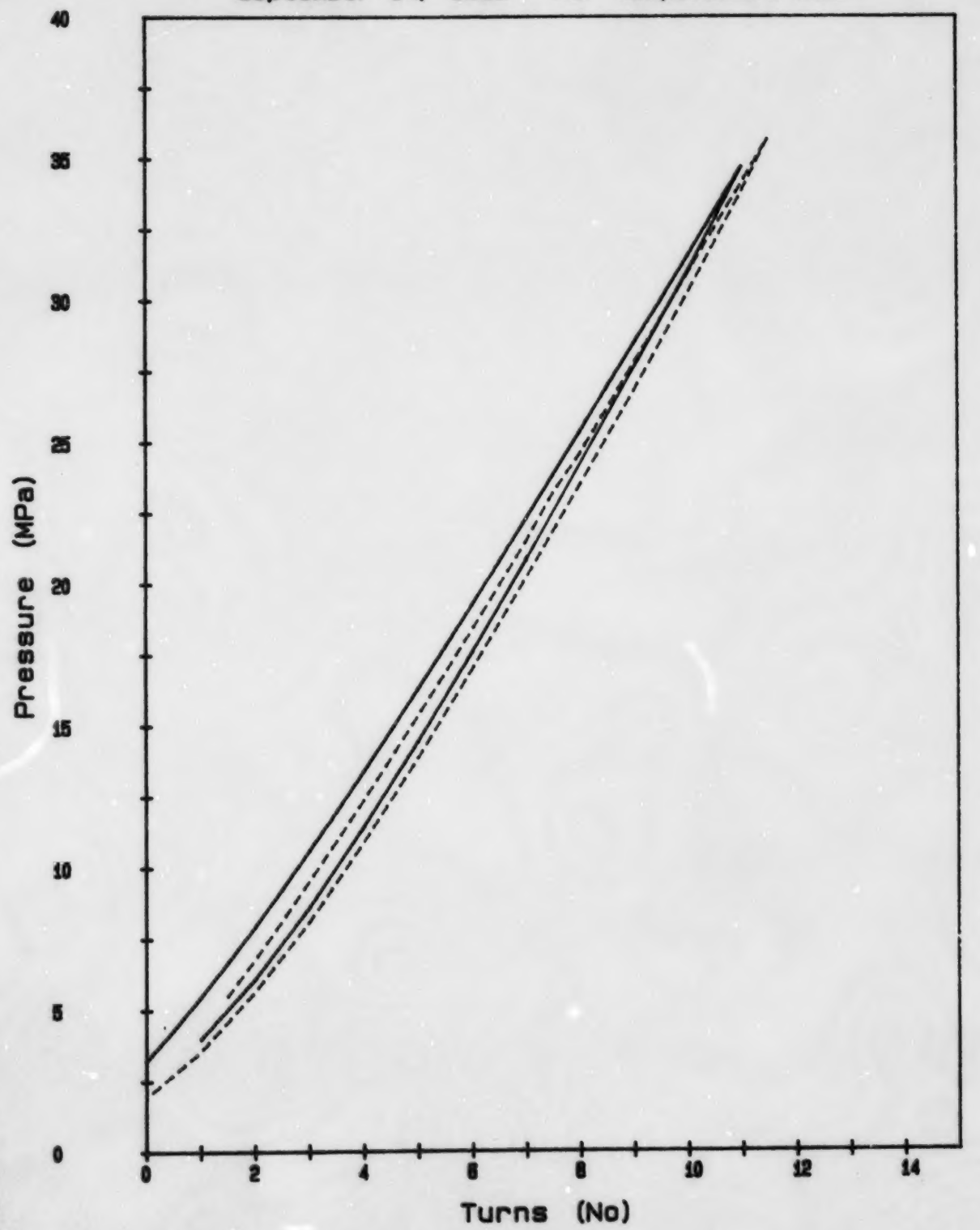

CSM Test Results (Georgian Bay)
Run 2
Run 3
Hole #1 Test #2 @ 2.7m
September 13, 1982 Air Temperature 25C
Pressure (MPa)
0
5
10
15
20
25
30
35
40
45
50
Turns (No)
0
10
20
30
40

84-169

CSM Test Results (Georgian Bay)



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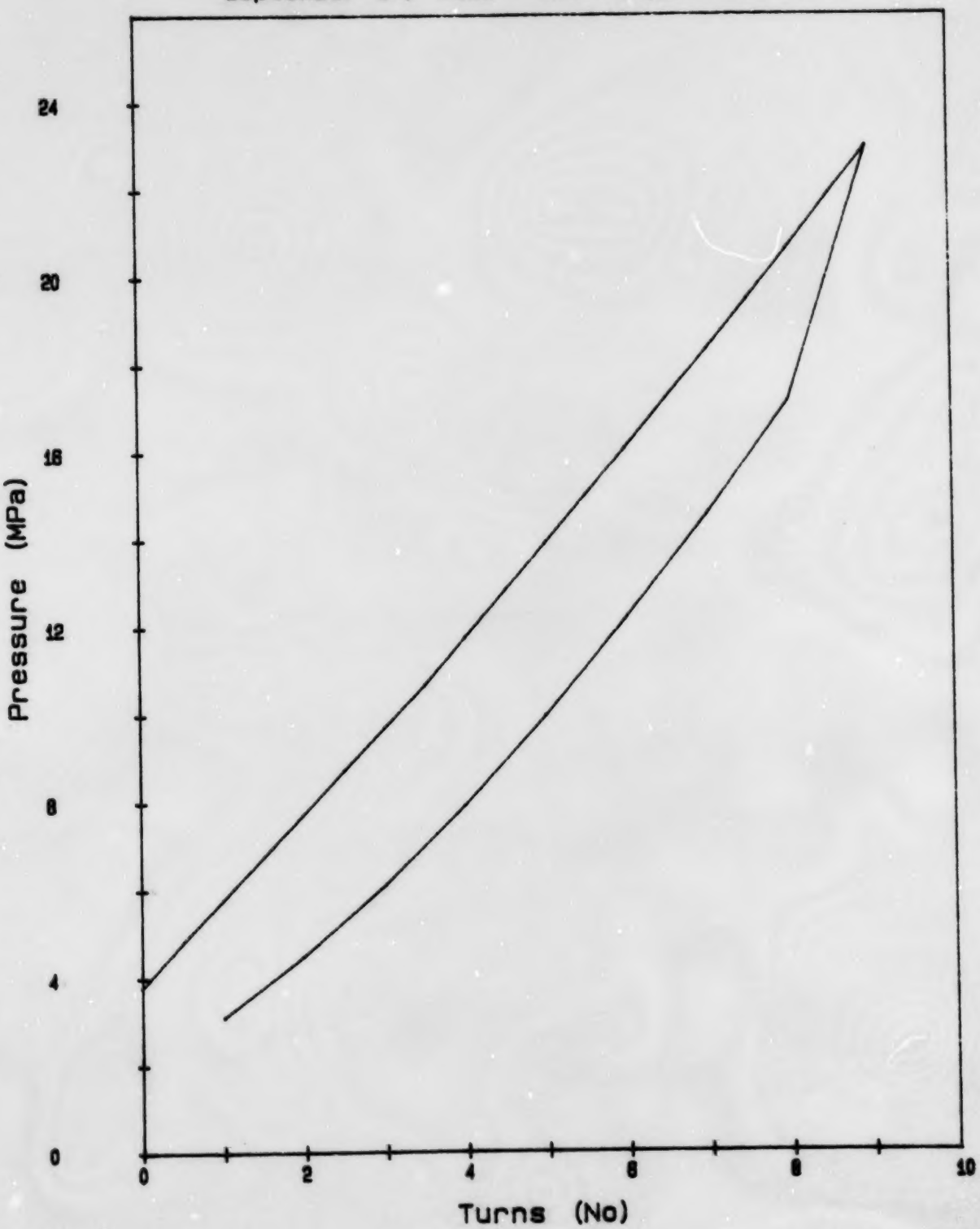
CSM Test Results (Georgian Bay)

Run 1 Hole #1 Test #4 @ 0.15m
September 14, 1982 Air Temperature 18C



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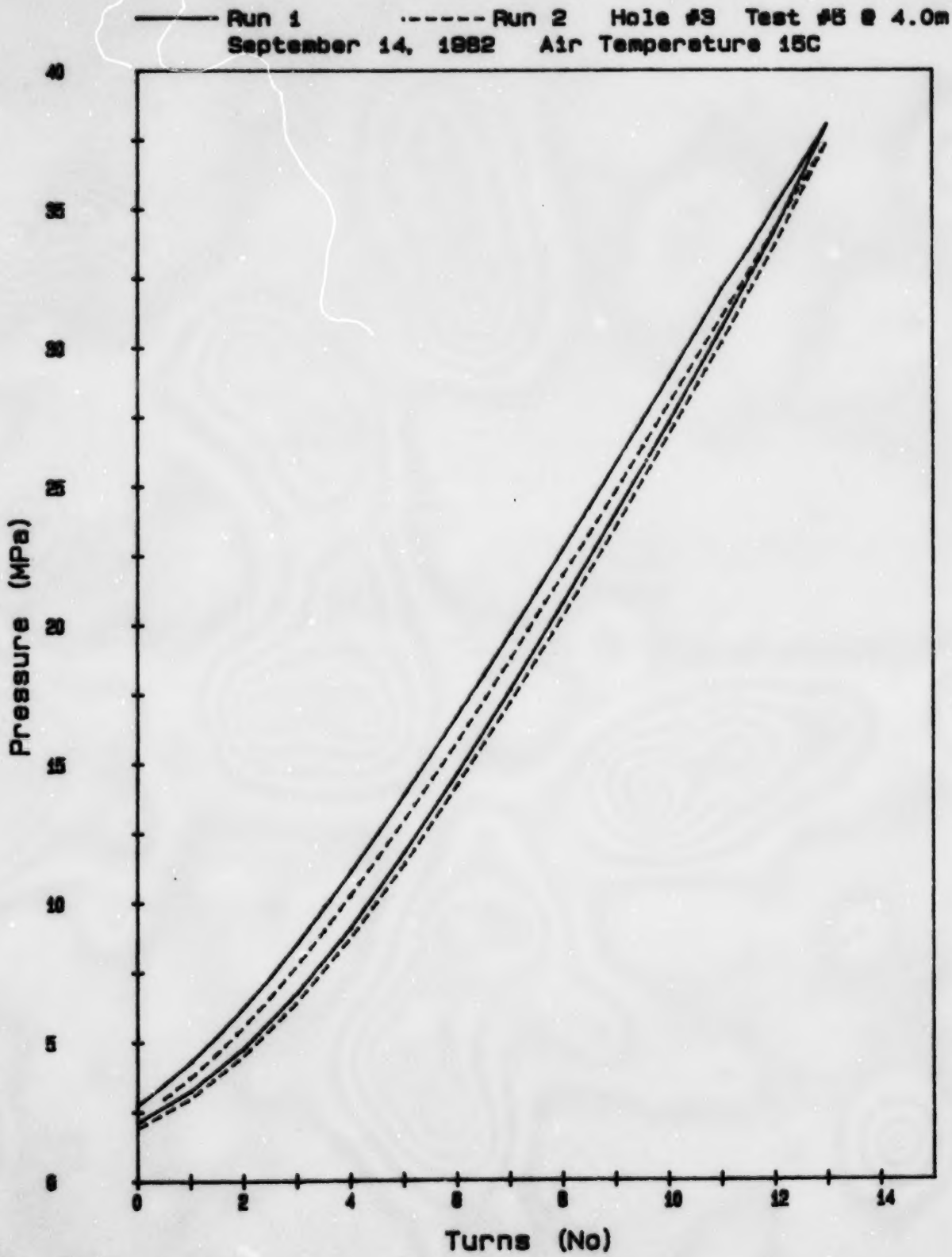
CSM Test Results (Georgian Bay)



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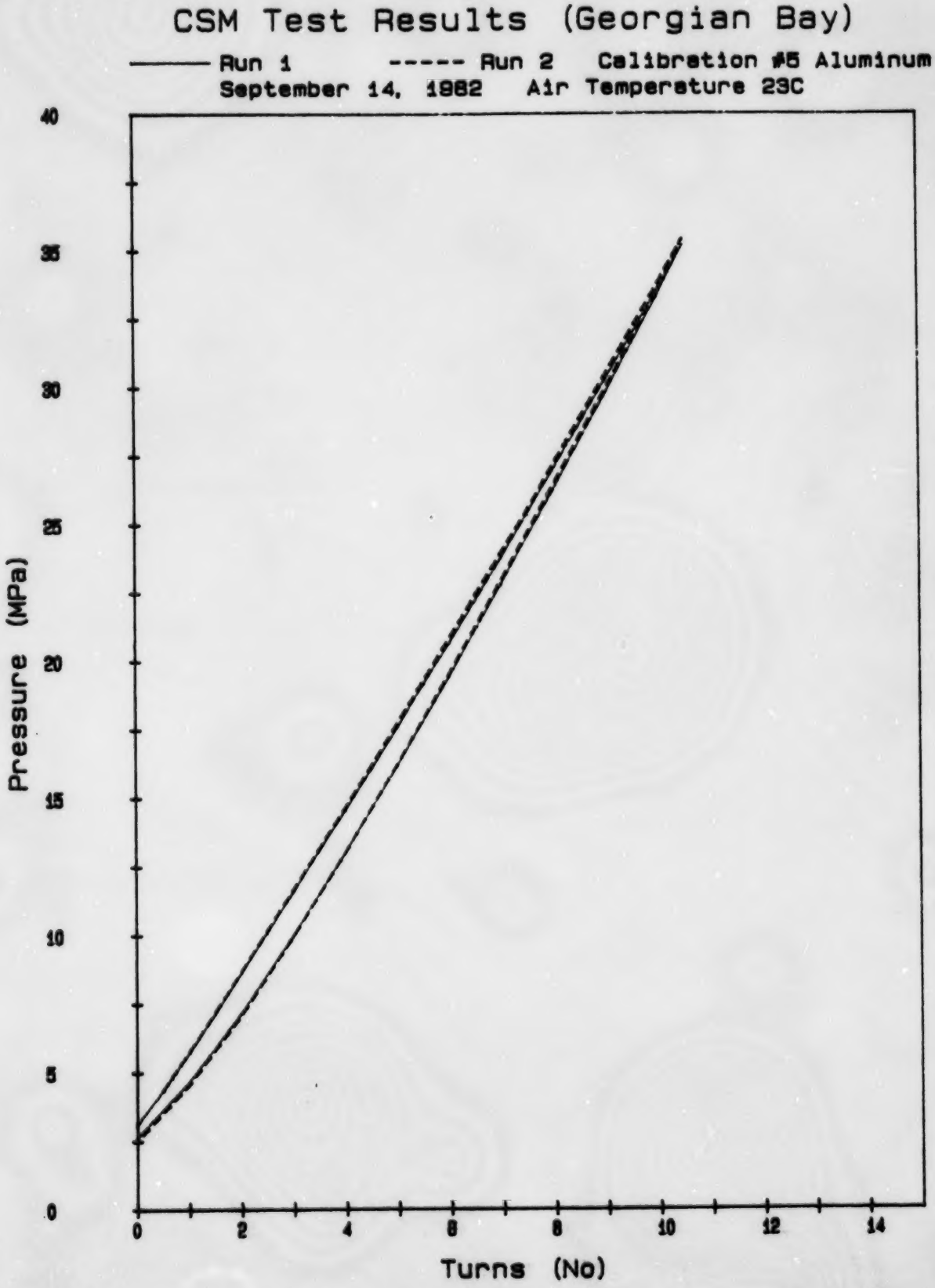
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Run 1
Run 2
Calibration #5 Aluminum
September 14, 1982
Air Temperature 23C
Pressure (MPa)
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10
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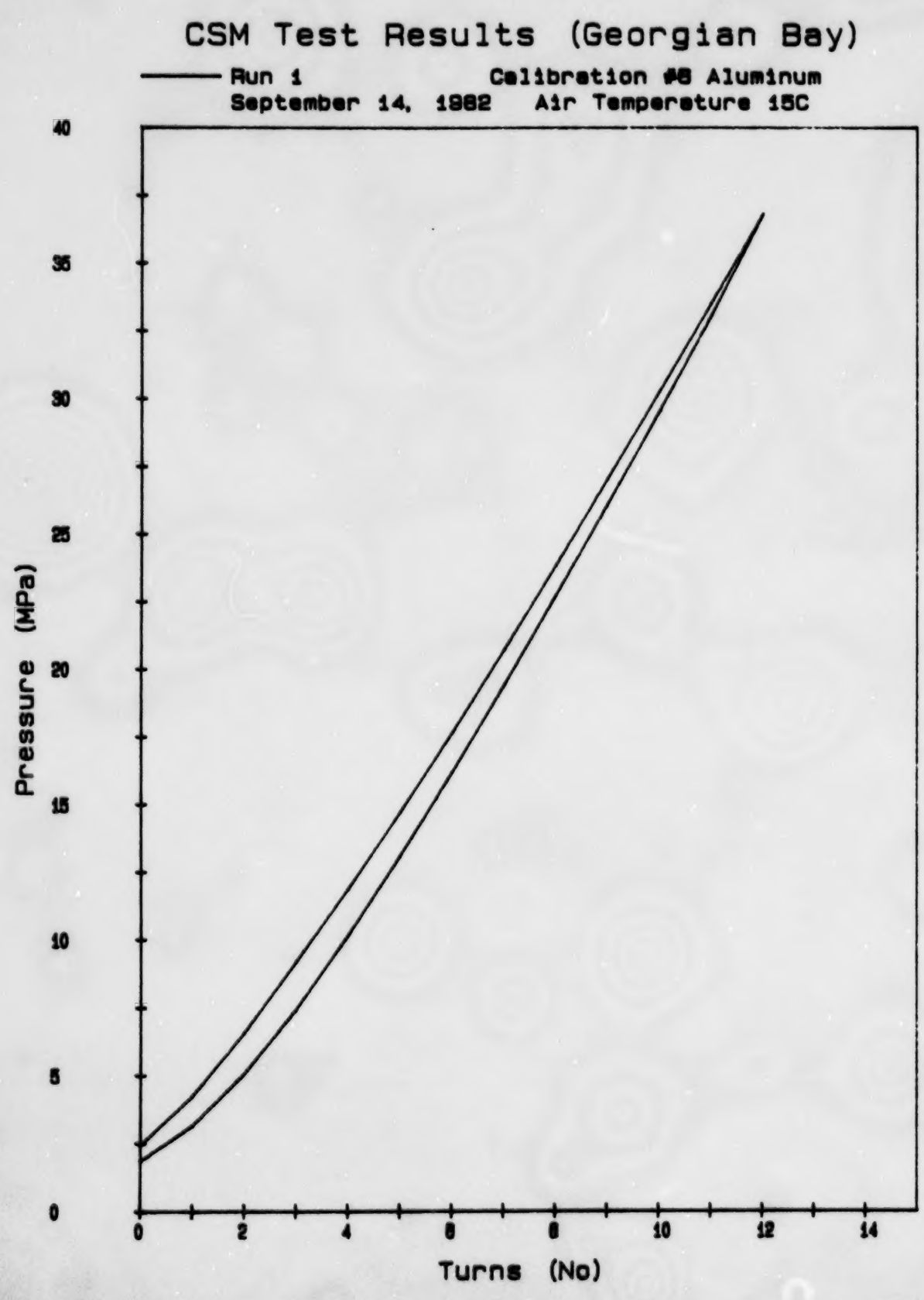
2
4
6
8
10
12
14
Turns (No)


CSM Test Results (Georgian Bay)
Run 1
Calibration #8 Aluminum
September 14, 1982
Air Temperature 15C
Pressure (MPa)
0
5
10
15
20
25
30
35
40
0
2
4
6
8
10
12
14
Turns (No)

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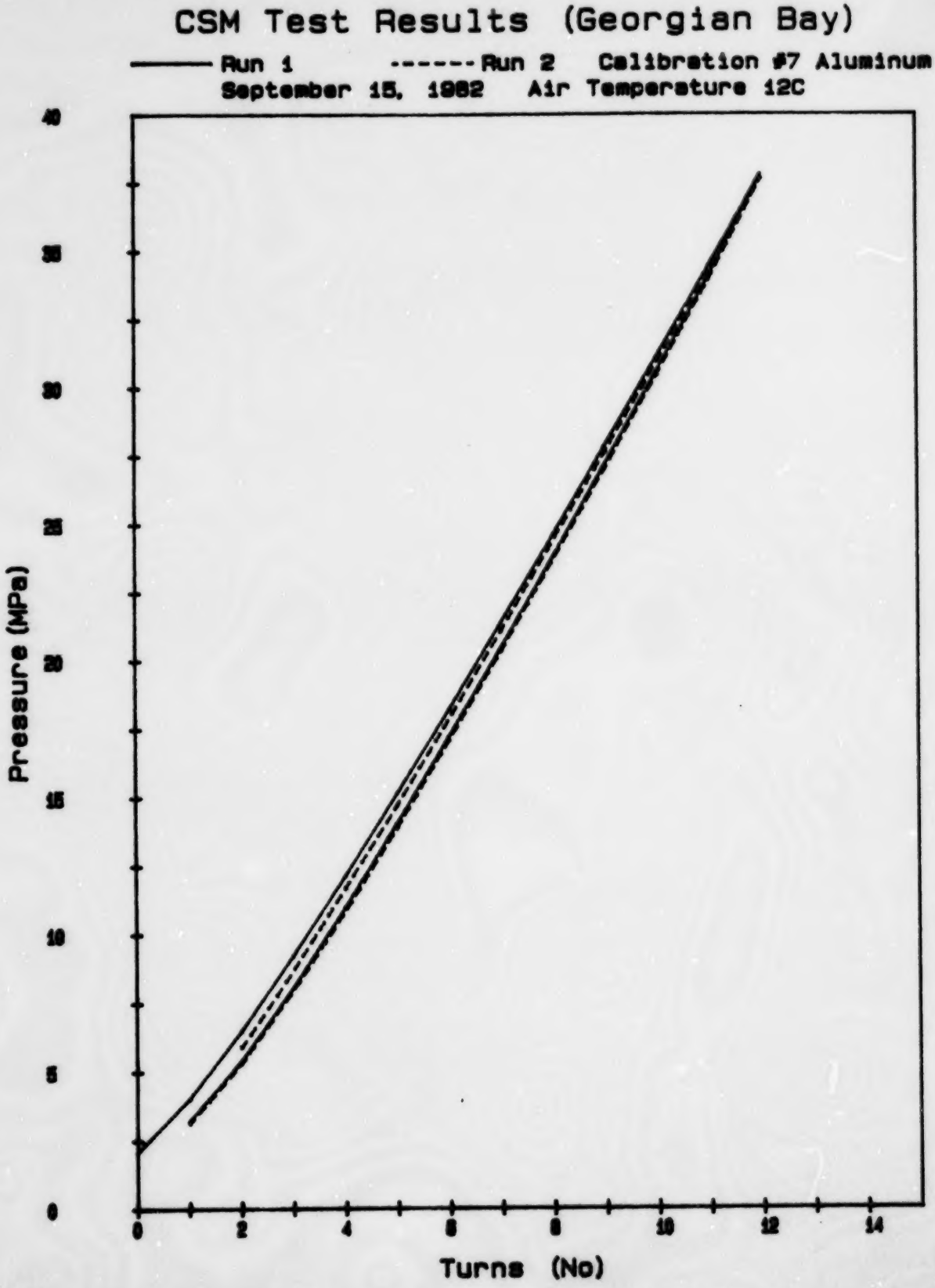
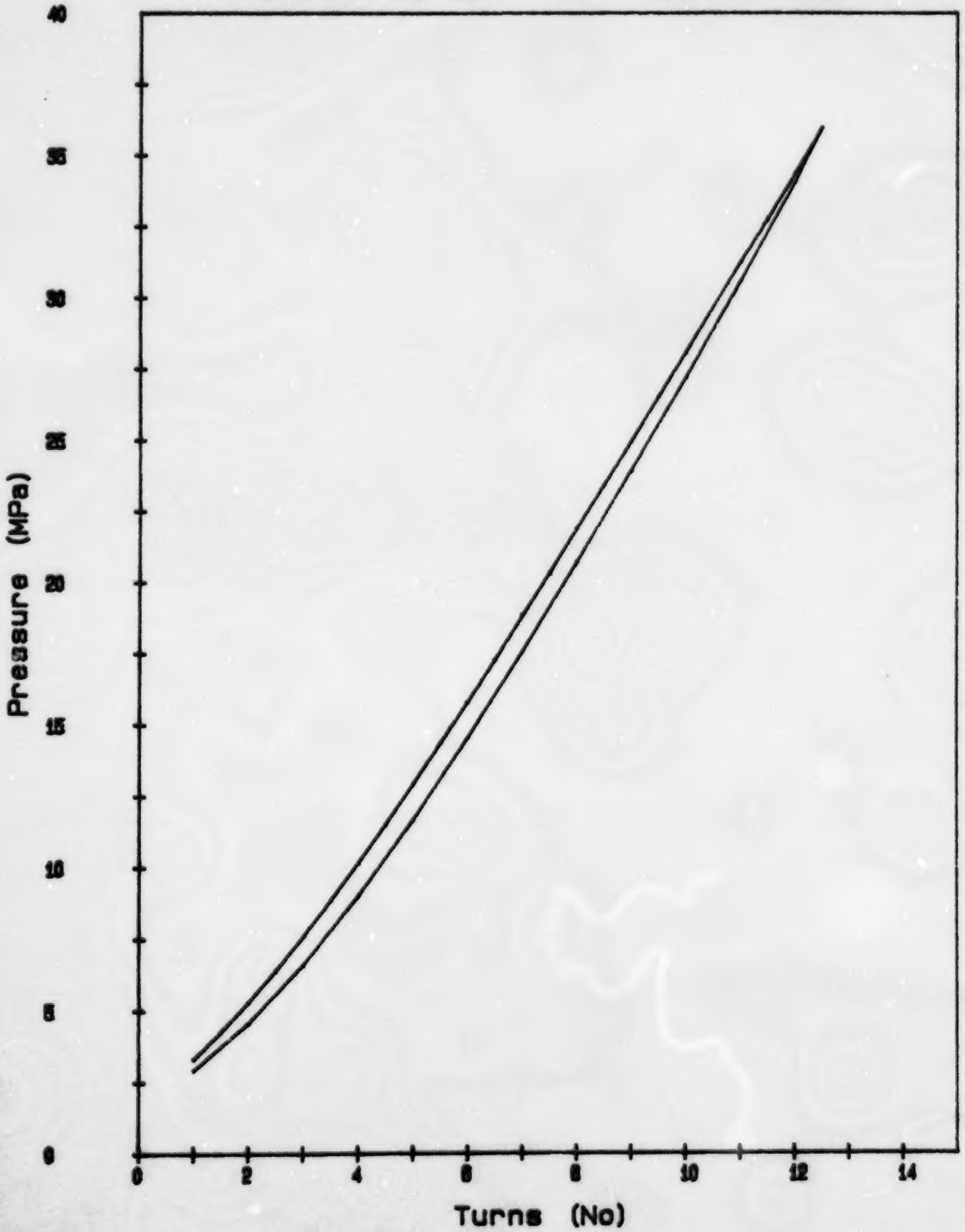

CSM Test Results (Georgian Bay)
Run 1
Run 2
Calibration #7 Aluminum
September 15, 1982
Air Temperature 12C
Pressure (MPa)
0
5
10
15
20
25
30
35
40
0
2
4
6
8
10
12
14
Turns (No)

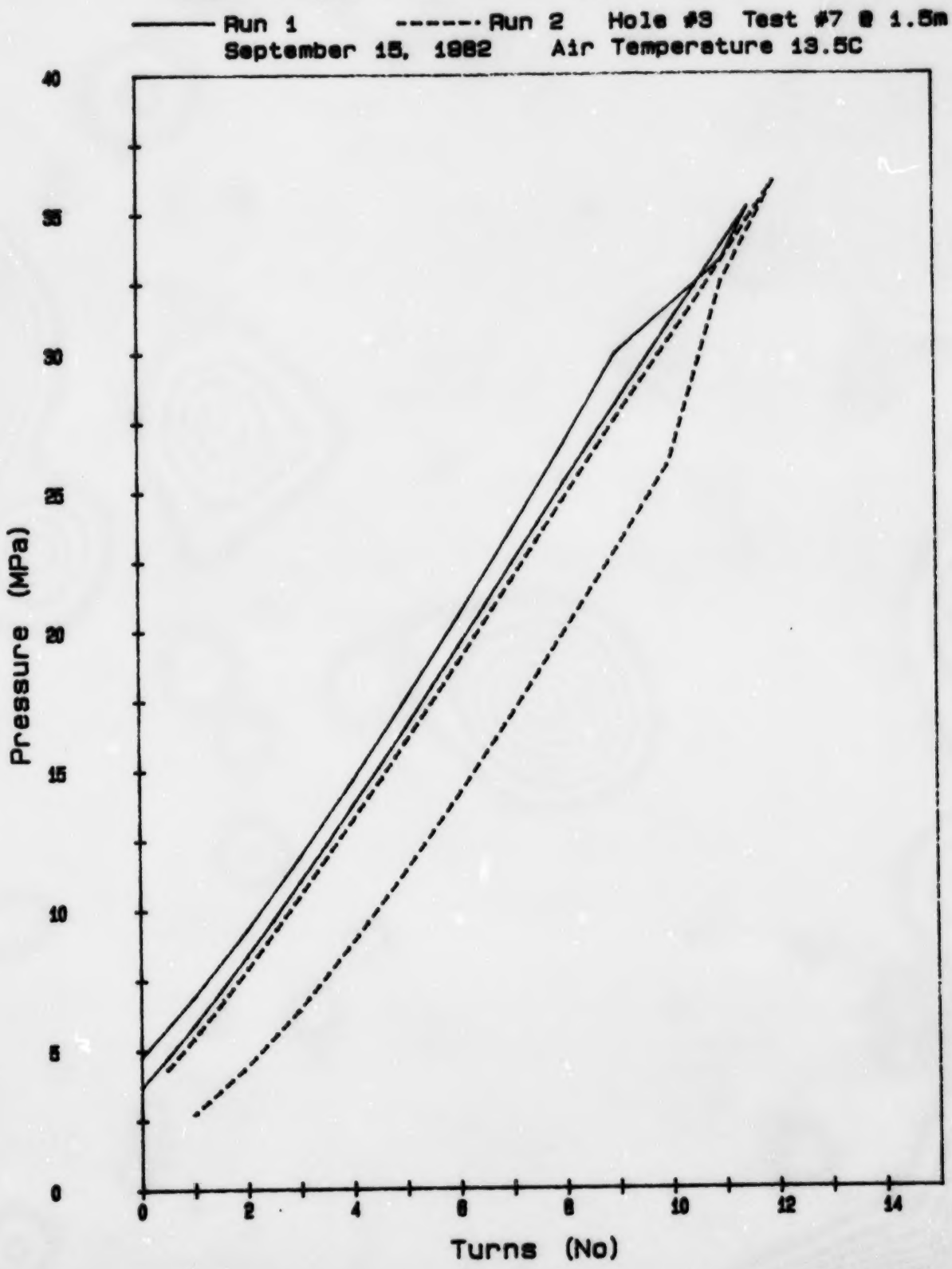
84-169

CSM Test Results (Georgian Bay)

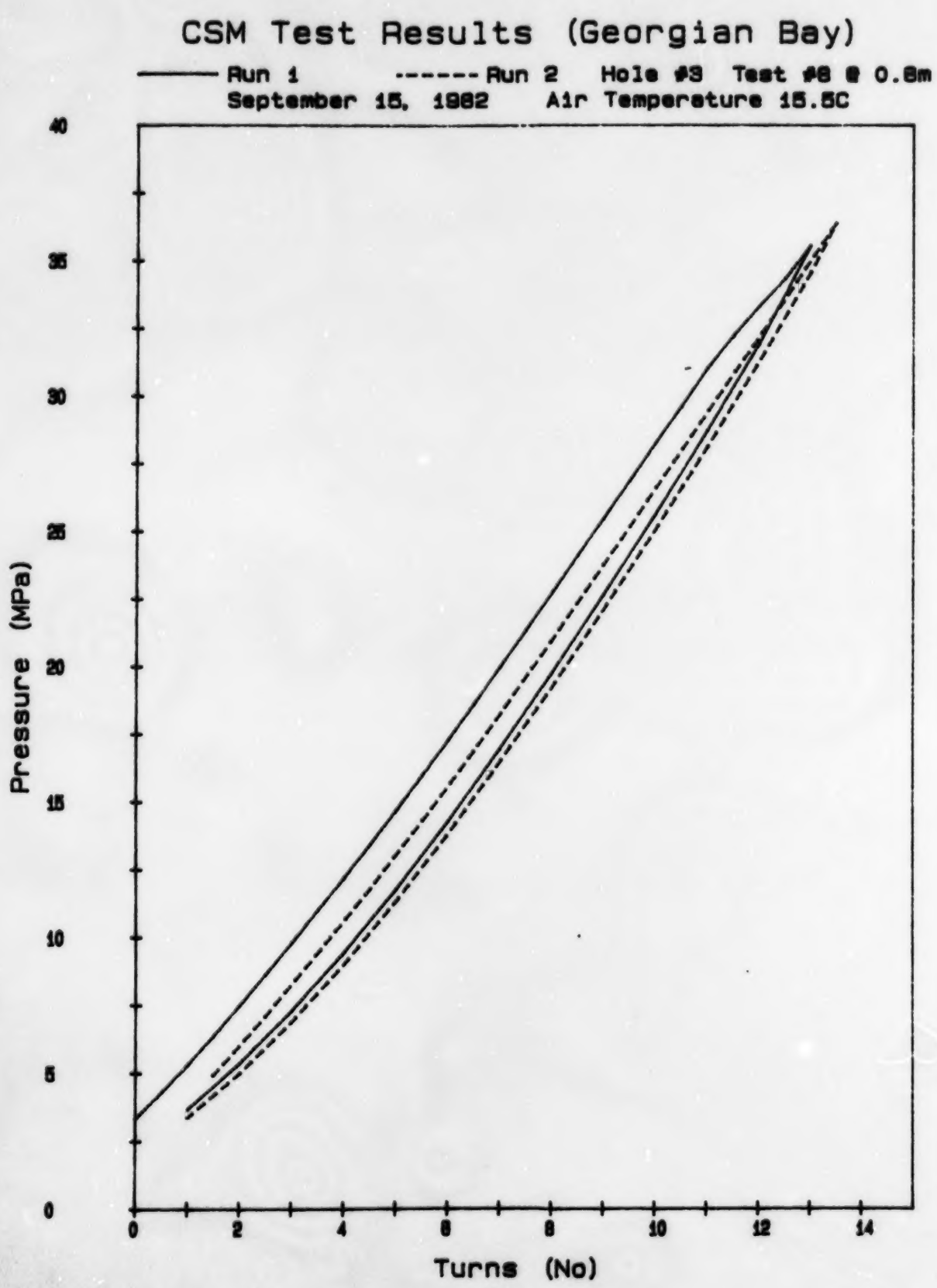
Run 1 Horizontal Hole #3 Test #6 @ 2.4m
September 15, 1982 Air Temperature 19C



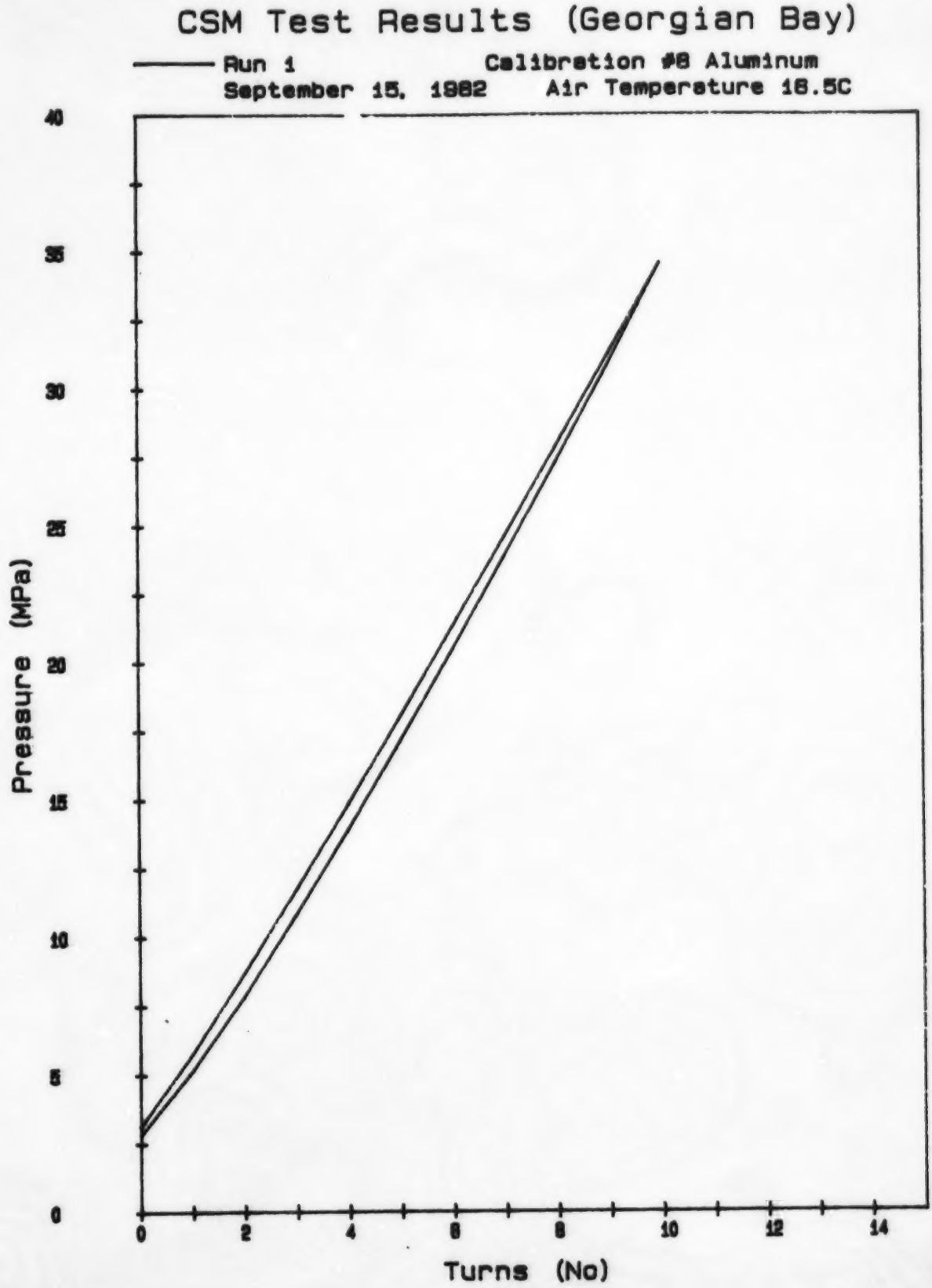
CSM Test Results (Georgian Bay)



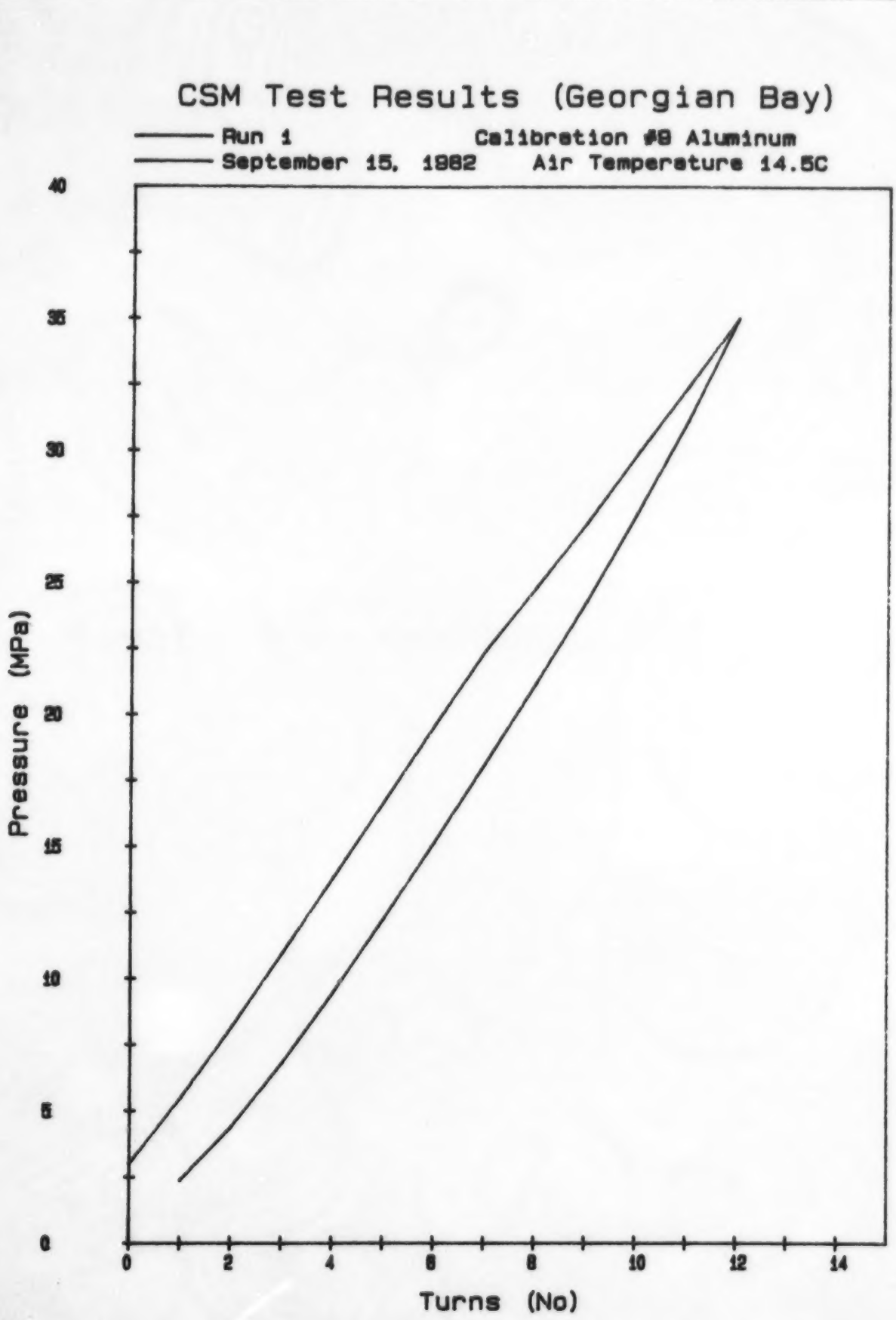
84-169


CSM Test Results (Georgian Bay)
Run 1
Run 2
Hole #3 Test #8 @ 0.8m
September 15, 1982
Air Temperature 15.5C
Pressure (MPa)
0
5
10
15
20
25
30
35
40
Turns (No)
0
2
4
6
8
10
12
14

84-169

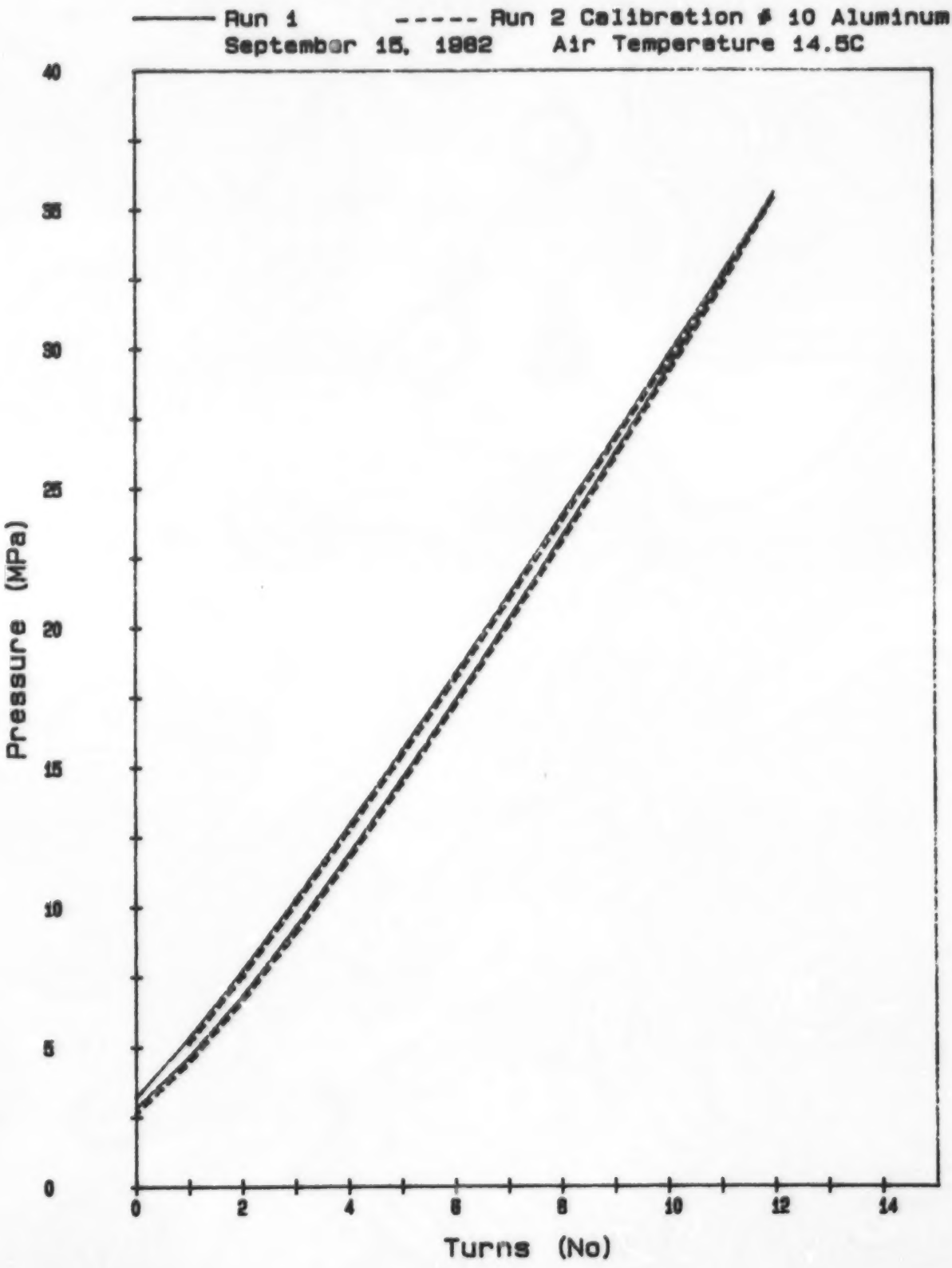

CSM Test Results (Georgian Bay)
Run 1
Calibration #8 Aluminum
September 15, 1982
Air Temperature 18.5C
Pressure (MPa)
0
5
10
15
20
25
30
35
40
Turns (No)
0
2
4
6
8
10
12
14

84-169

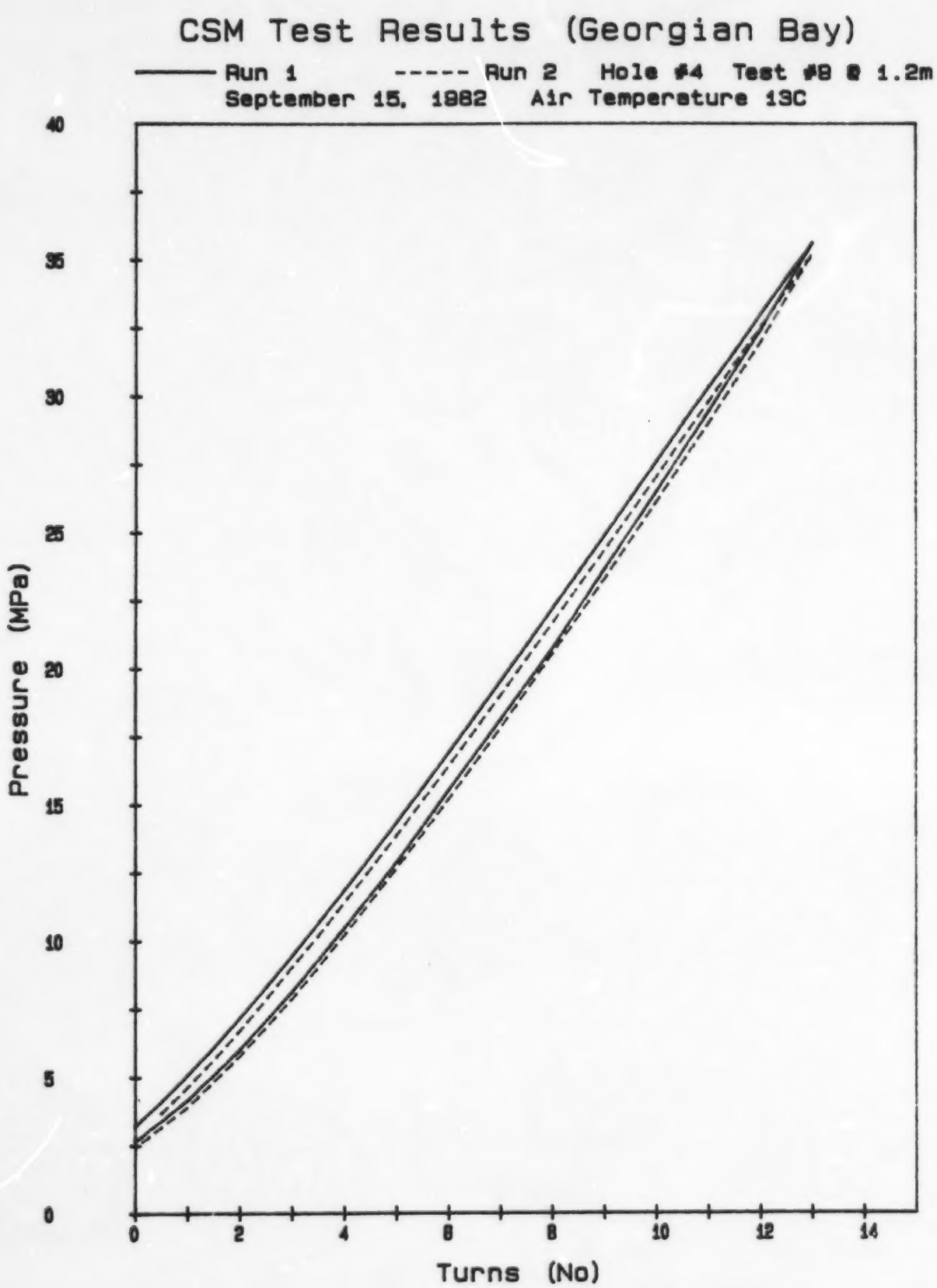

CSM Test Results (Georgian Bay)
Run 1
September 15, 1982
Calibration #8 Aluminum
Air Temperature 14.5C
Pressure (MPa)
0
5
10
15
20
25
30
35
40
0
2
4
6
8
10
12
14
Turns (No)

84-169

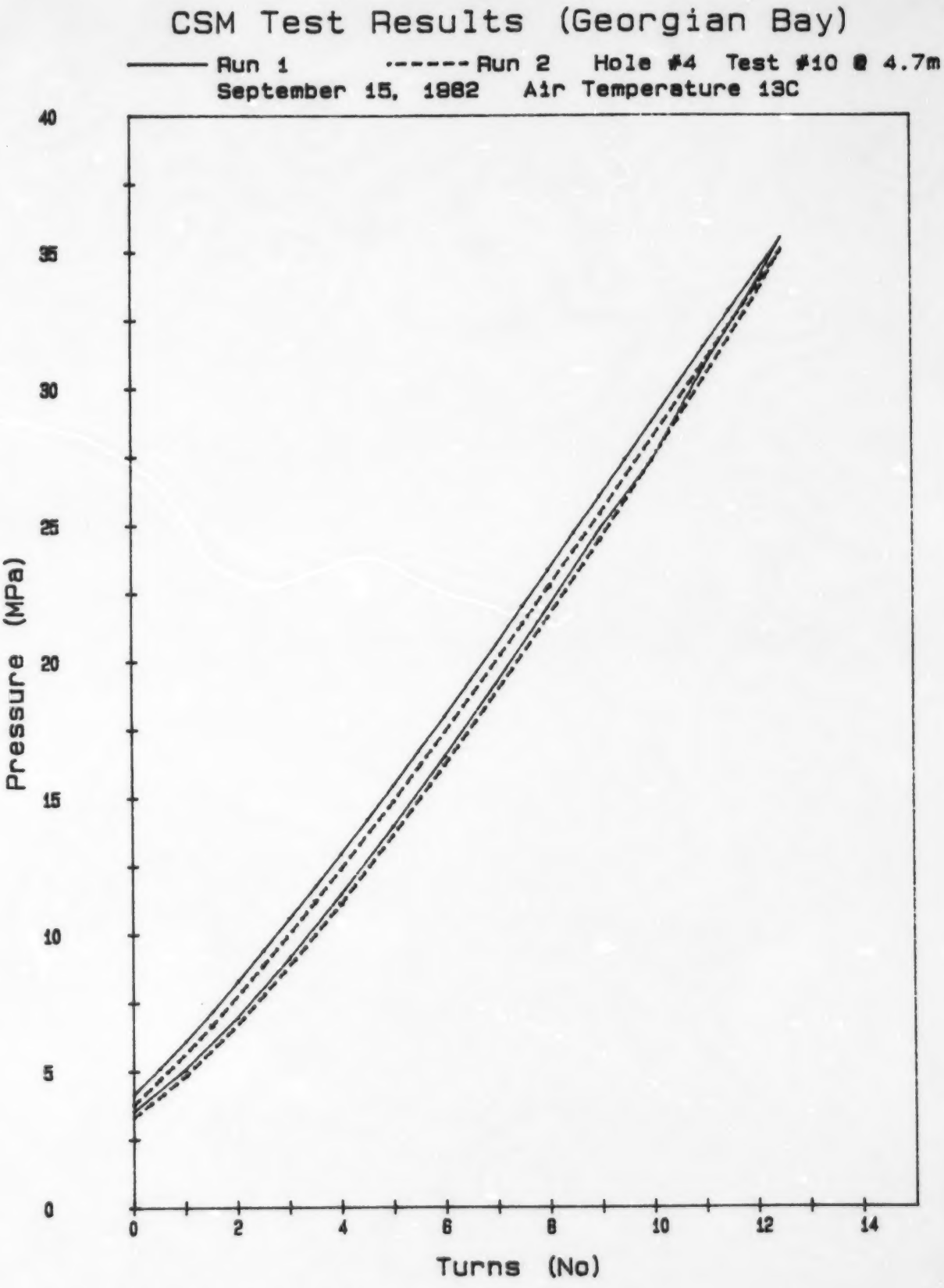
CSM Test Results (Georgian Bay)

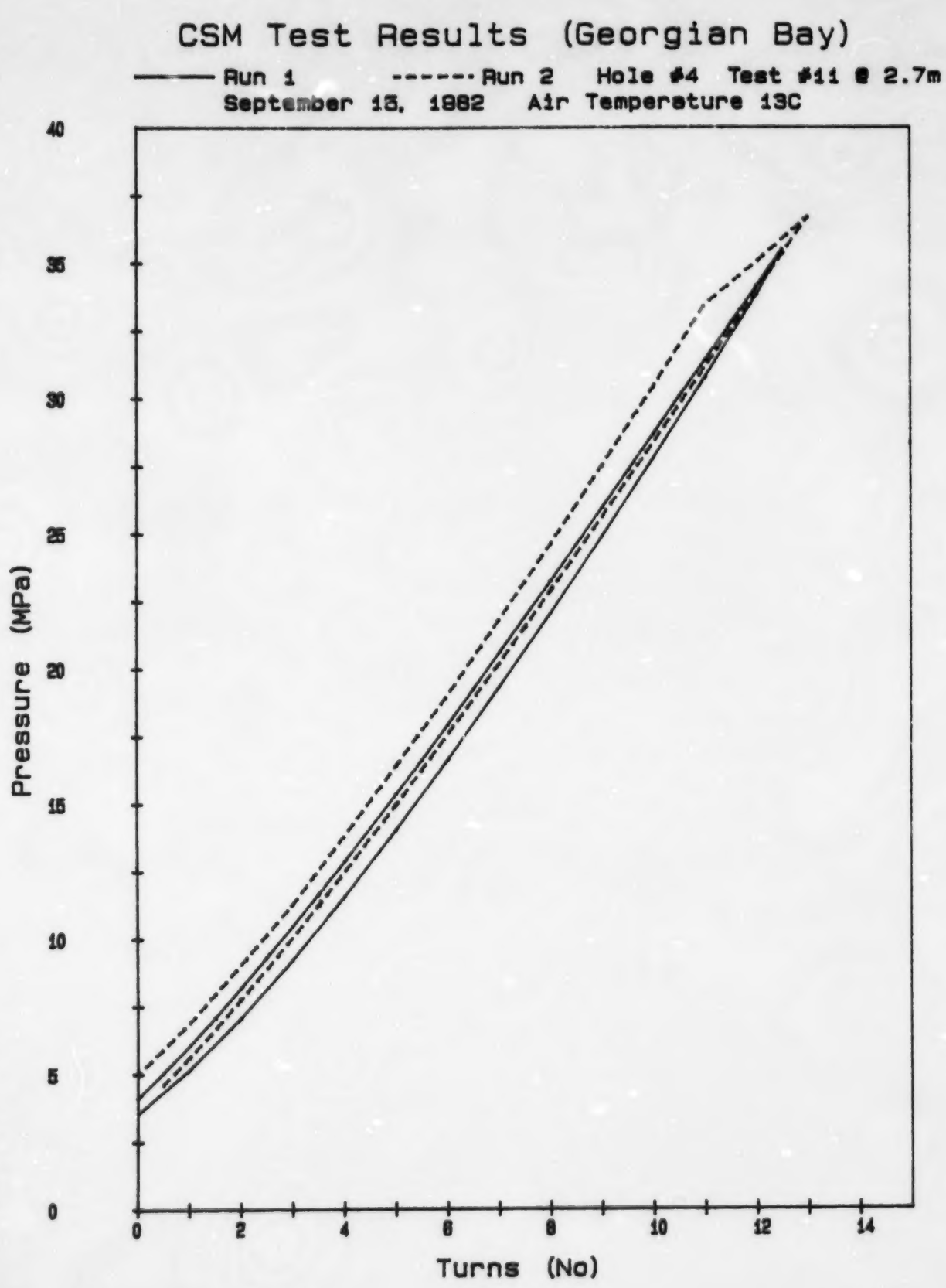


84-169

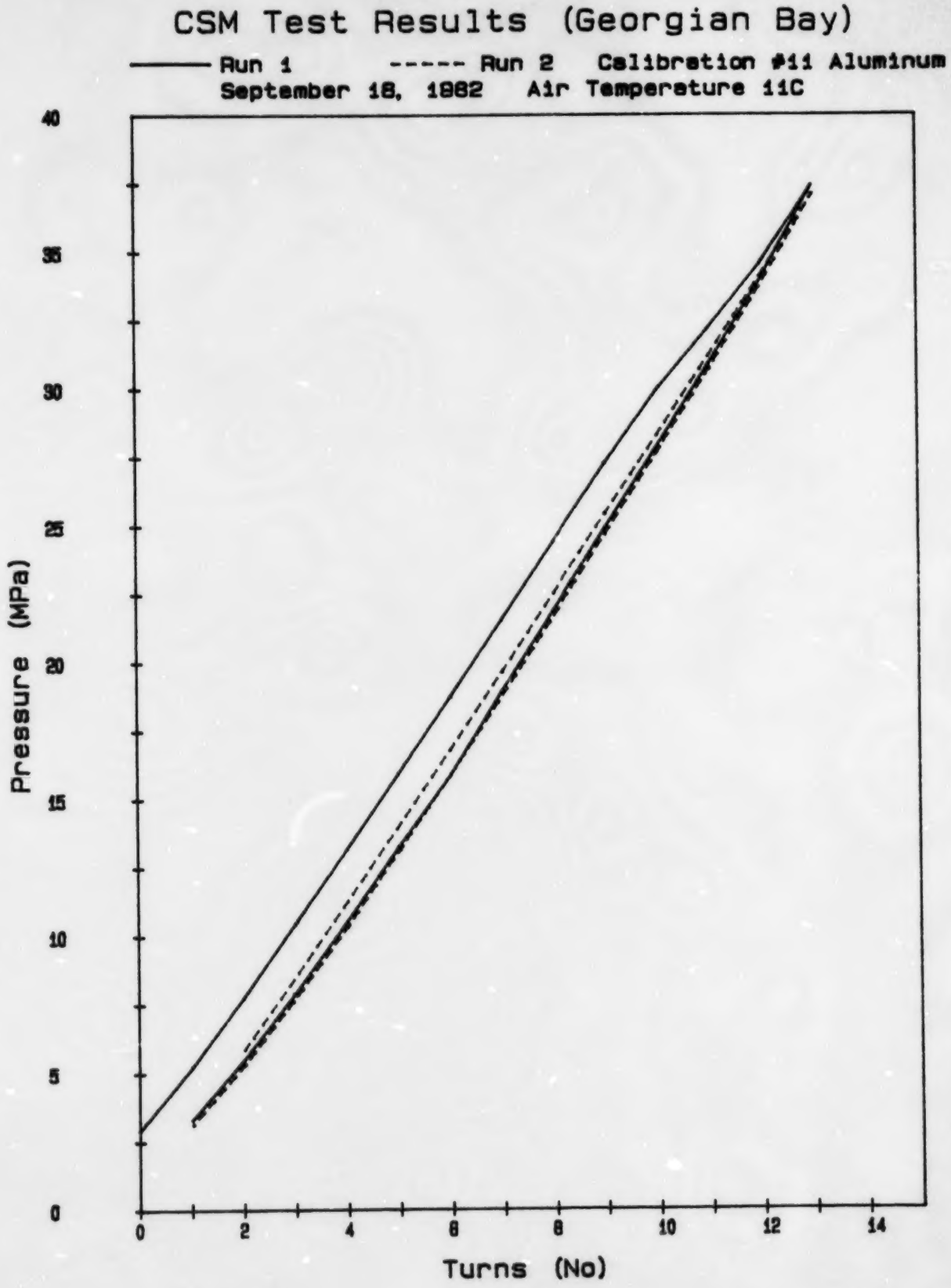

CSM Test Results (Georgian Bay)
Run 1
Run 2
Hole #4 Test #8 @ 1.2m
September 15, 1982 Air Temperature 13C
Pressure (MPa)
0
5
10
15
20
25
30
35
40
0
2
4
6
8
10
12
14
Turns (No)

84-169

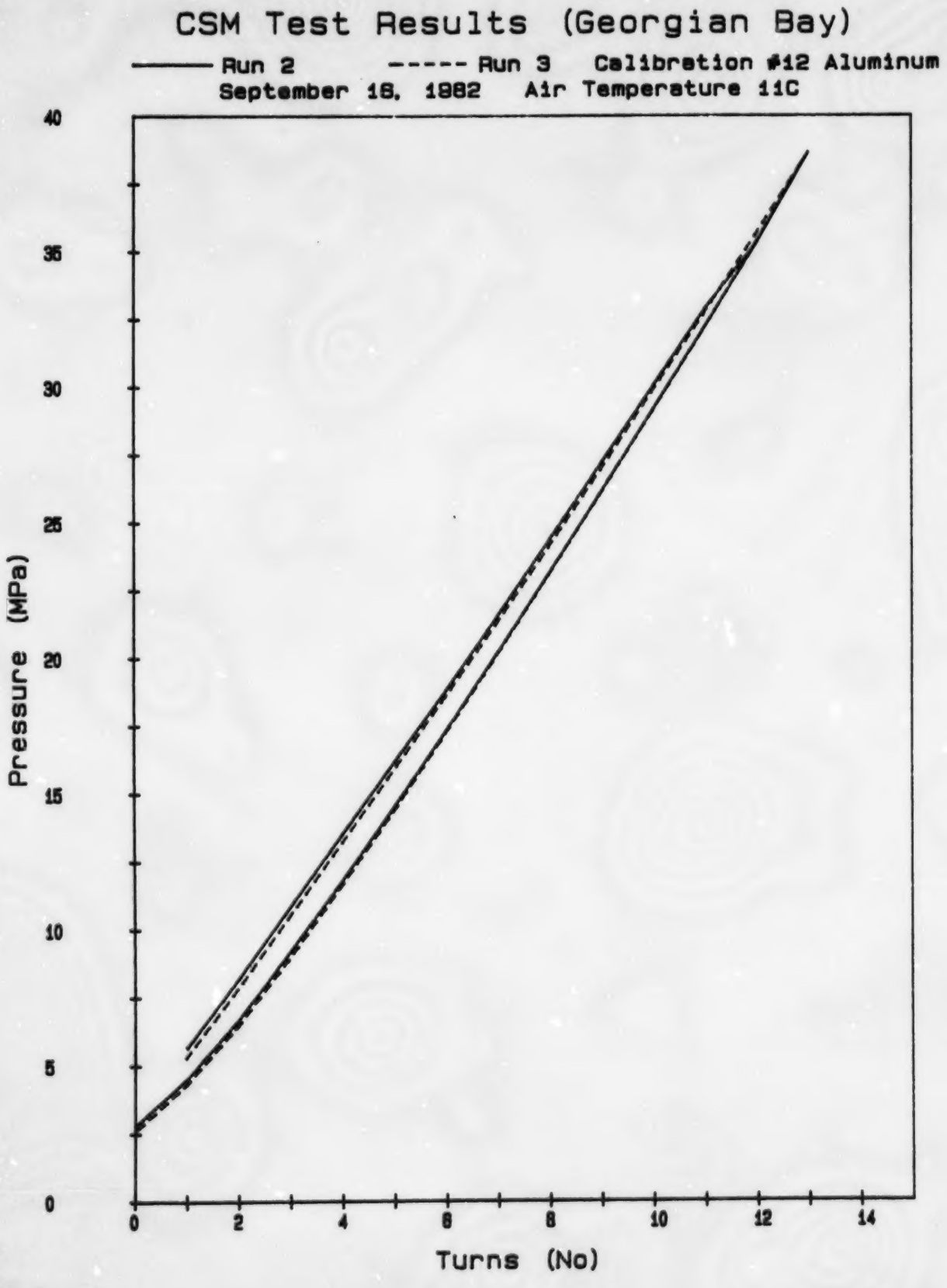

CSM Test Results (Georgian Bay)
Run 1
Run 2
Hole #4 Test #10 @ 4.7m
September 15, 1982 Air Temperature 13C
Pressure (MPa)
0
5
10
15
20
25
30
35
40
Turns (No)
0
2
4
6
8
10
12
14


CSM Test Results (Georgian Bay)
Run 1
Run 2
Hole #4 Test #11 @ 2.7m
September 15, 1982 Air Temperature 13C
Pressure (MPa)
0
5
10
15
20
25
30
35
40
0
2
4
6
8
10
12
14
Turns (No)

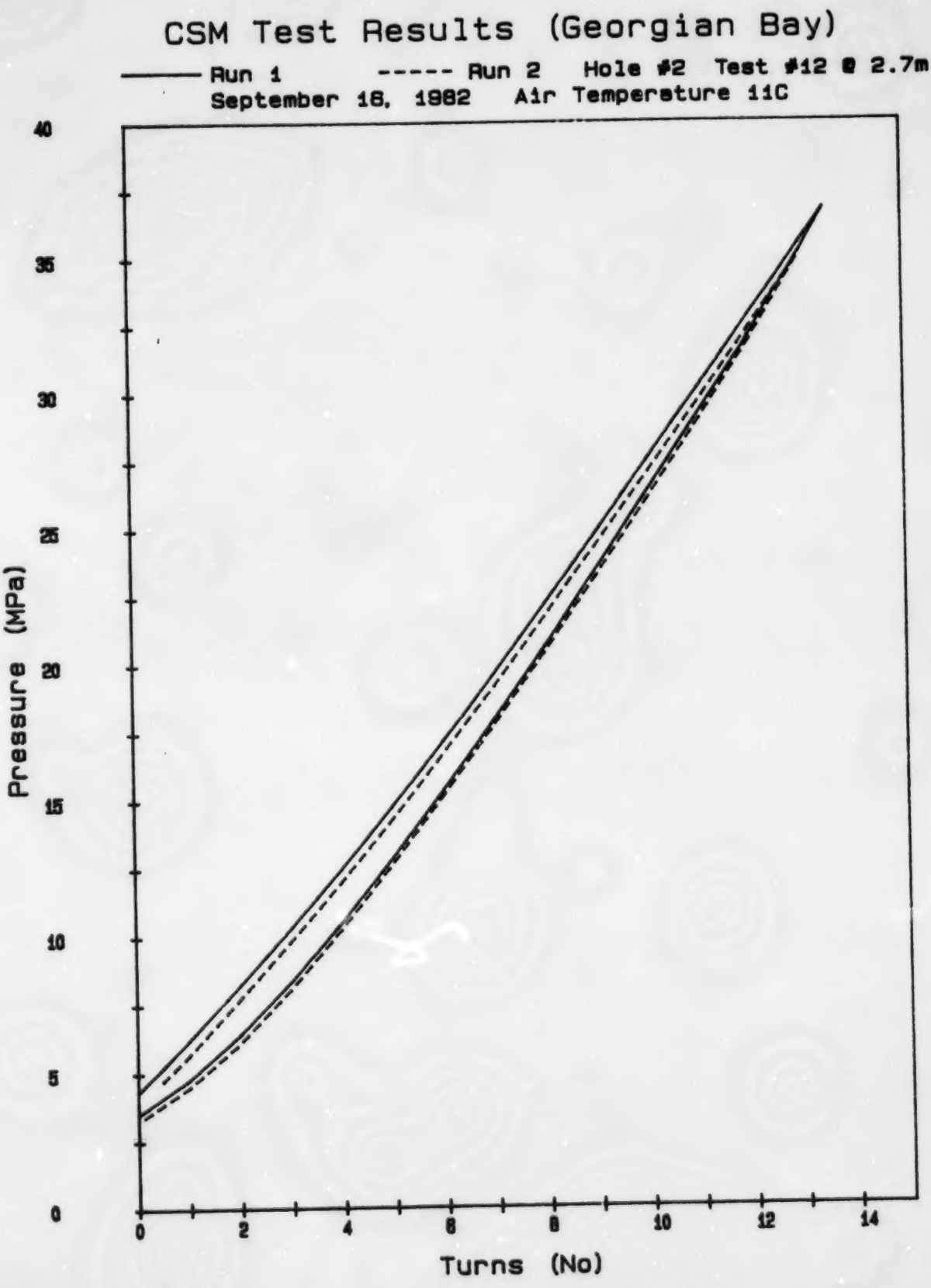
84-169


CSM Test Results (Georgian Bay)
Run 1
Run 2
Calibration #11 Aluminum
September 18, 1982
Air Temperature 11C
Pressure (MPa)
0
5
10
15
20
25
30
35
40
Turns (No)
0
2
4
6
8
10
12
14

84-169


CSM Test Results (Georgian Bay)
Run 2
Run 3
Calibration #12 Aluminum
September 18, 1982
Air Temperature 11C
Pressure (MPa)
0
5
10
15
20
25
30
35
40
0
2
4
6
8
10
12
14
Turns (No)

84-169


CSM Test Results (Georgian Bay)
Run 1
Run 2
Hole #2 Test #12 @ 2.7m
September 18, 1982 Air Temperature 11C
Pressure (MPa)
0
5
10
15
20
25
30
35
40
0
2
4
6
8
10
12
14
Turns (No)

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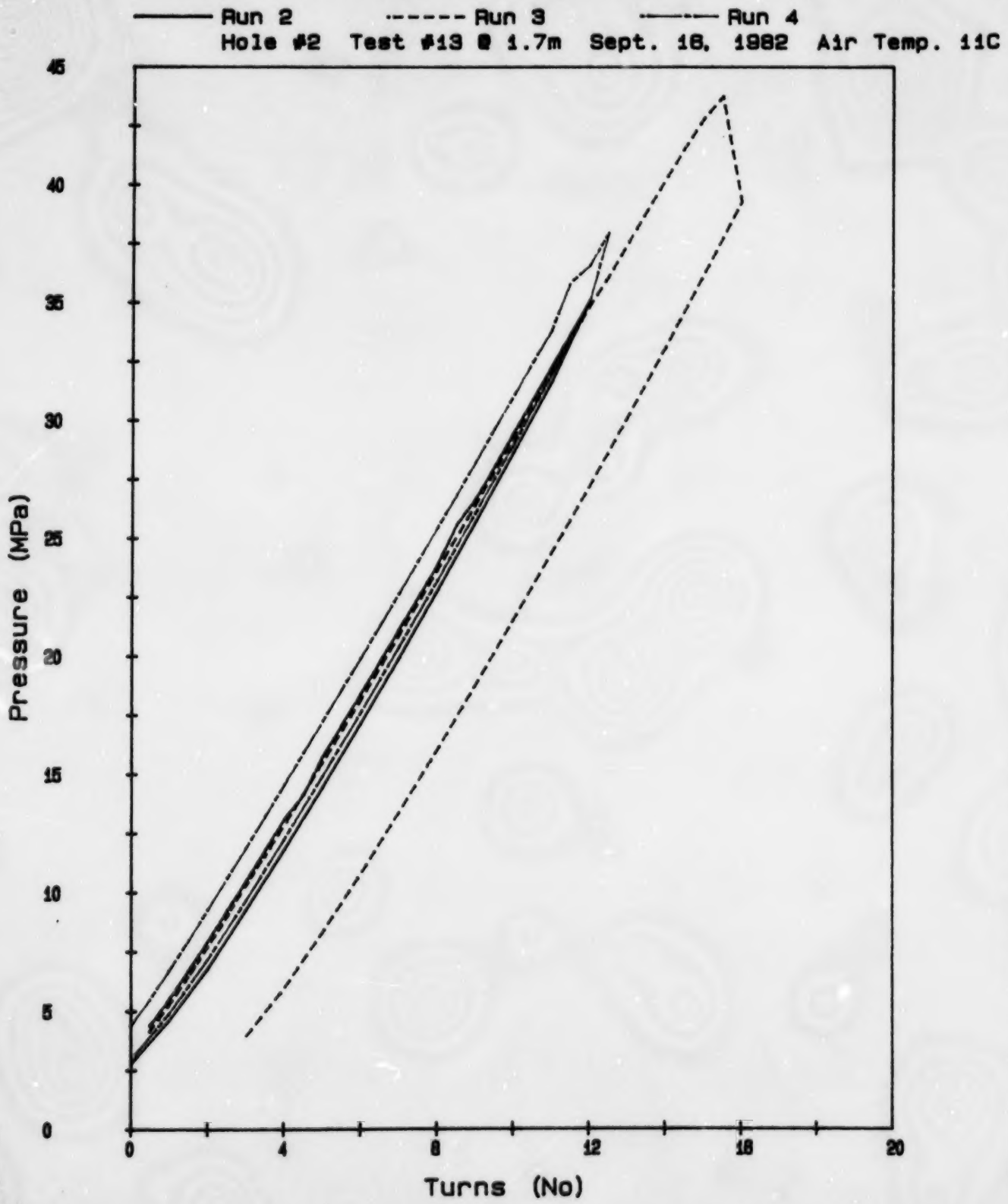
CSM Test Results (Georgian Bay)



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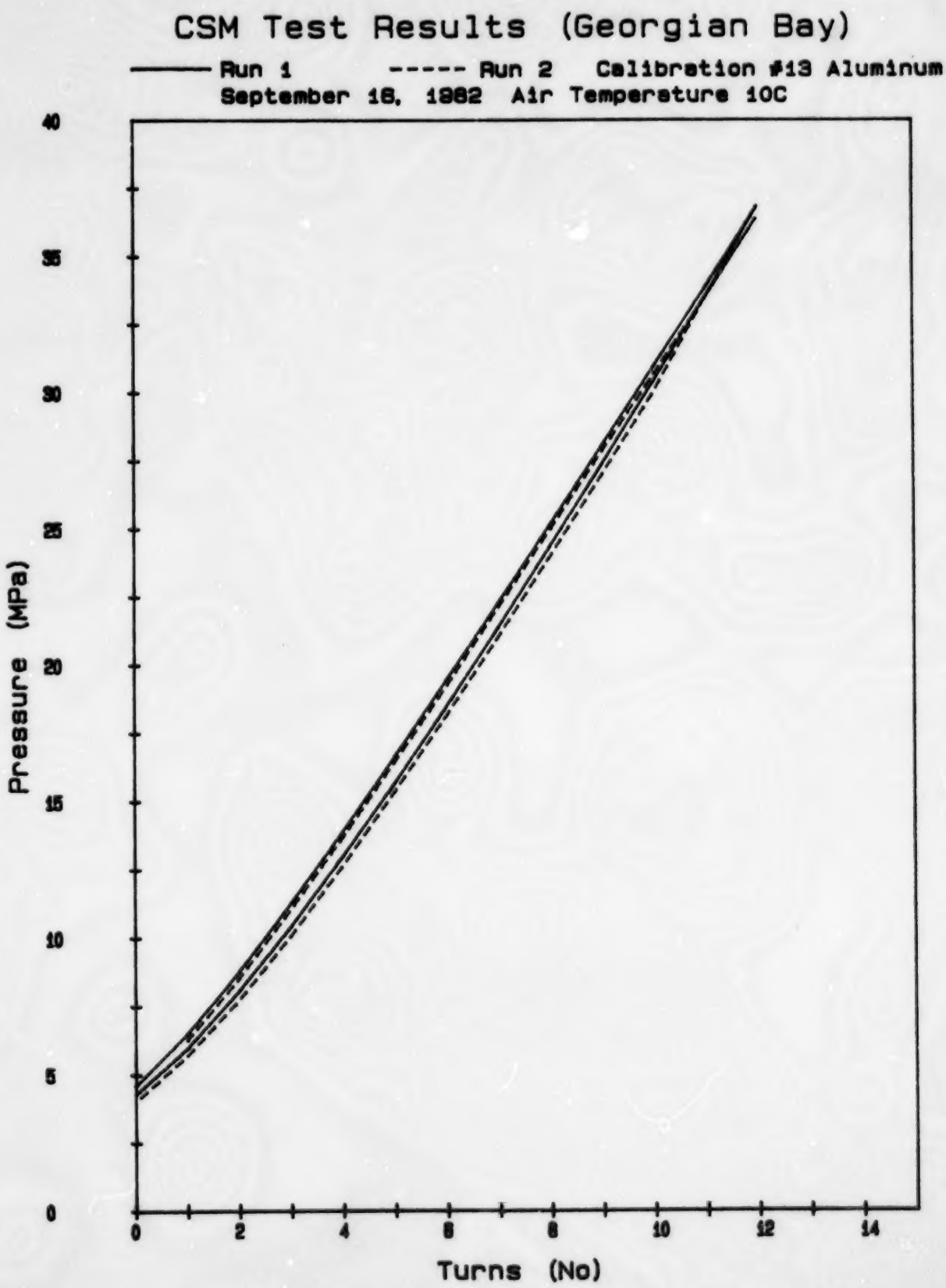
CSM Test Results (Georgian Bay)
Run 1
Run 2
Calibration #13 Aluminum
September 16, 1982 Air Temperature 10C
Pressure (MPa)
0
5
10
15
20
25
30
35
40
0
2
4
6
8
10
12
14
Turns (No)

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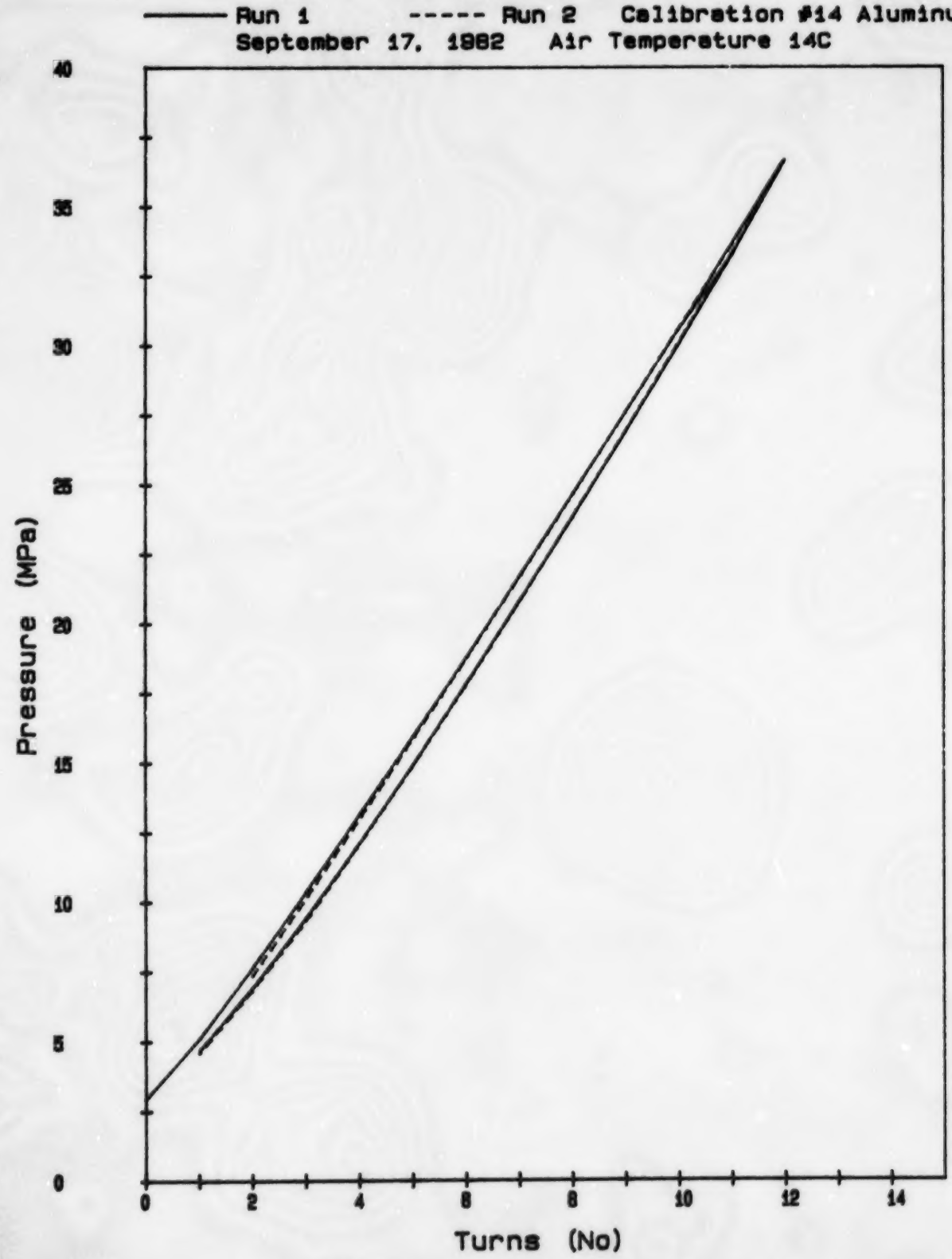
CSM Test Results (Georgian Bay)



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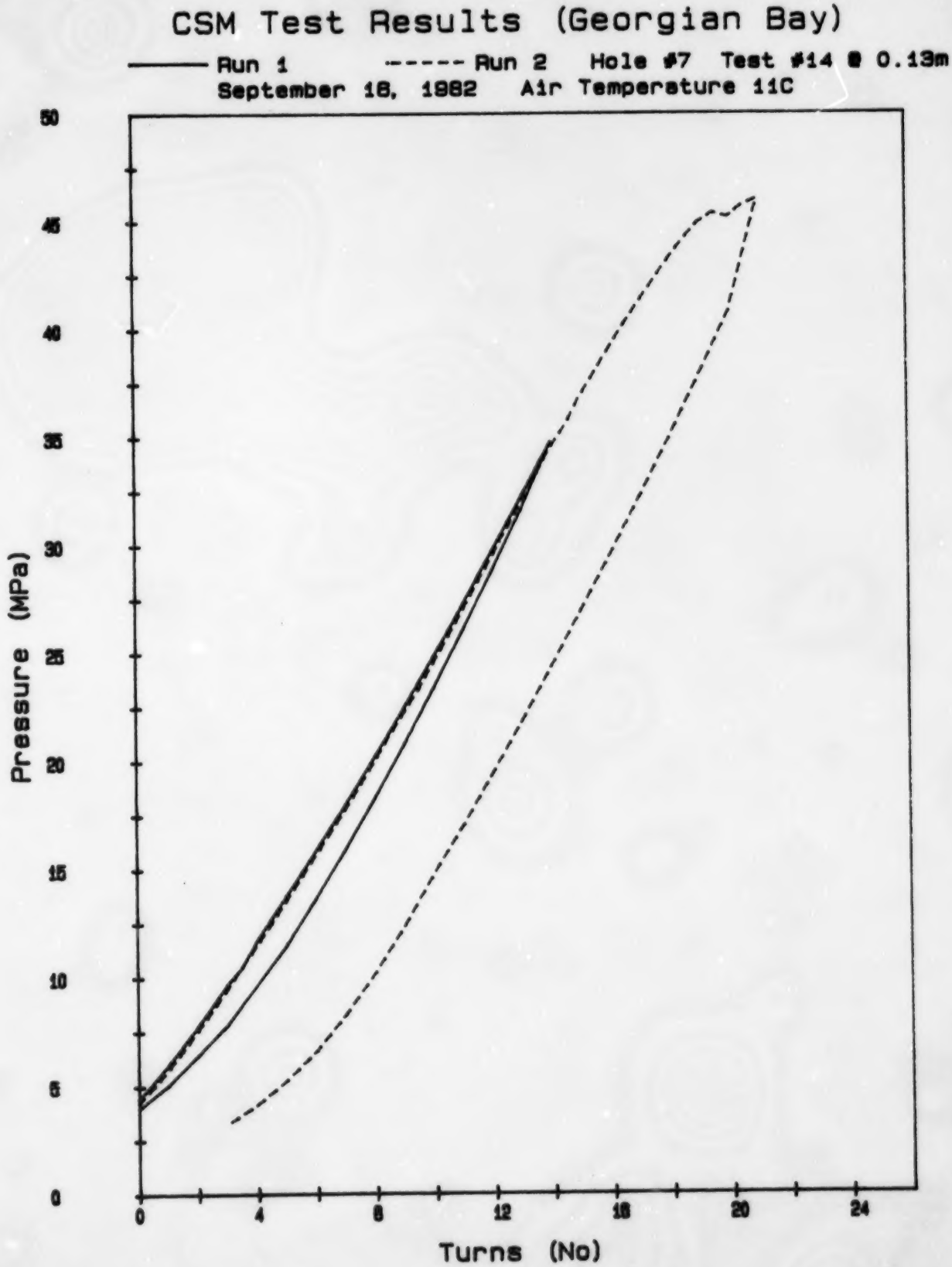
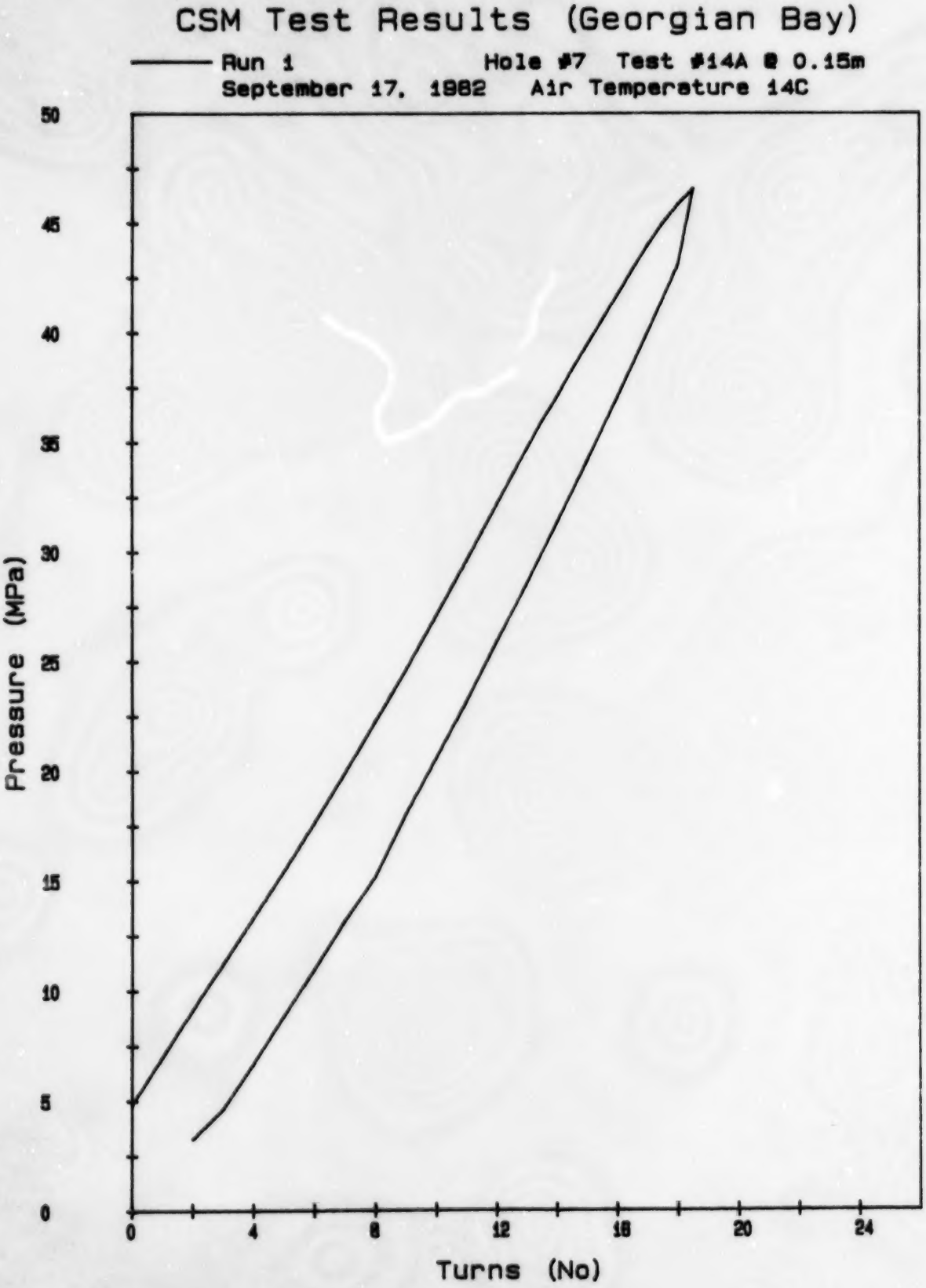
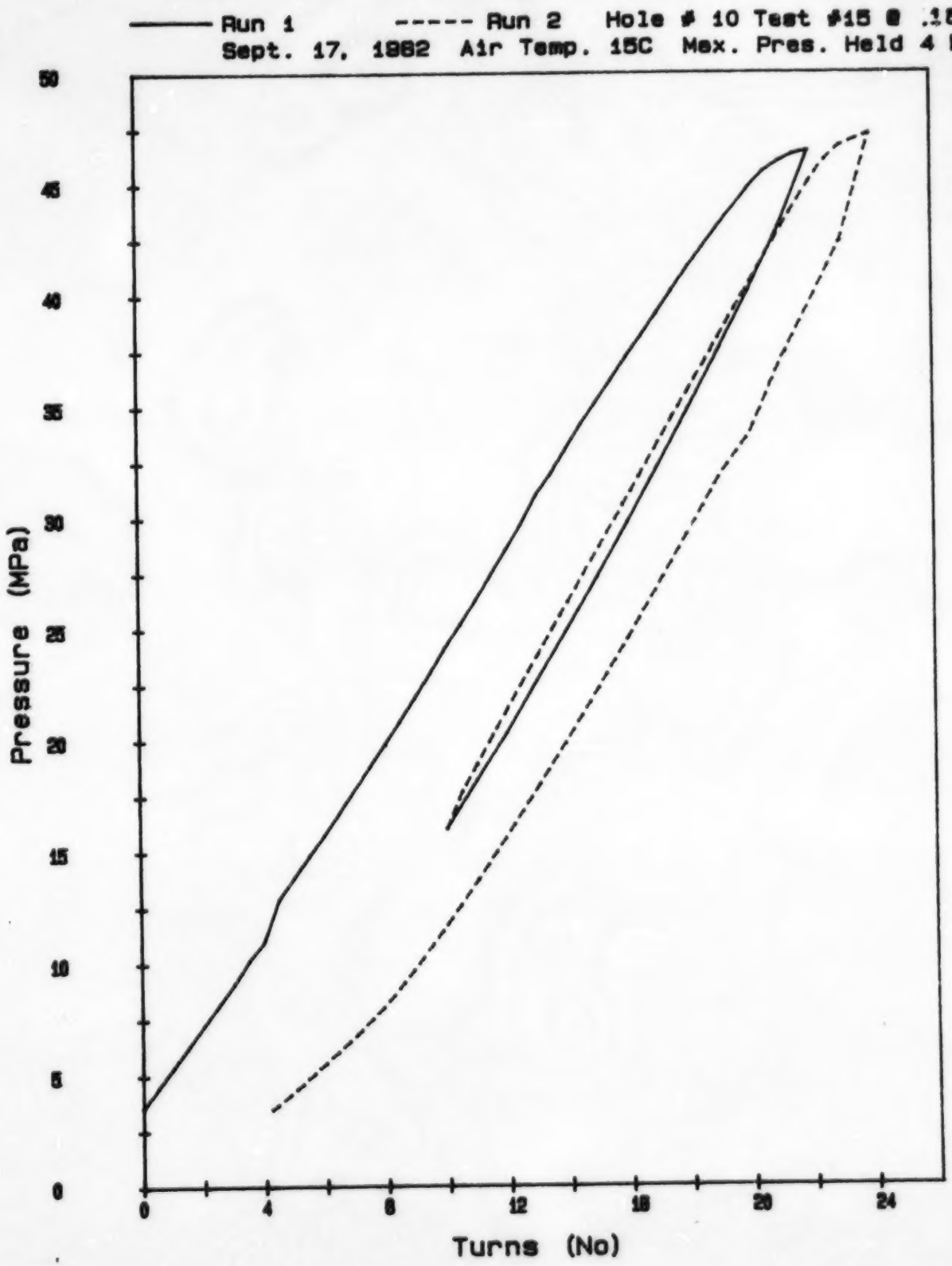

CSM Test Results (Georgian Bay)
Run 1
Run 2
Hole #7 Test #14 @ 0.13m
September 18, 1982 Air Temperature 11C
Pressure (MPa)
0
5
10
15
20
25
30
35
40
45
50
Turns (No)
0
4
8
12
16
20
24

84-169


CSM Test Results (Georgian Bay)
Run 1
Hole #7 Test #14A @ 0.15m
September 17, 1982 Air Temperature 14C
Pressure (MPa)
0
5
10
15
20
25
30
35
40
45
50
0
4
8
12
16
20
24
Turns (No)

84-169

CSM Test Results (Georgian Bay)



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